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# THE CRINOIDEA FLEXIBILIA

(With an Atlas of A. B. C. and 76 Plates)

BY

FRANK SPRINGER

LAS VEGAS, NEW MEXICO

ASSOCIATE IN PALEONTOLOGY, U. S. NATIONAL MUSEUM

TEXT

(Publication 2501)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION
1920

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To the memory of CHARLES WACHSMUTH, joint author of the Monograph of the North American Crinoidea Camerata, collaborator and friend of my early years, this work is dedicated by

FRANK SPRINGER.

WASHINGTON, *June* 1, 1918.

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# THE CRINOIDEA FLEXIBILIA

By FRANK SPRINGER

ASSOCIATE IN PALEONTOLOGY, U. S. NATIONAL MUSEUM

## INTRODUCTION

It is a fresh illustration of the growth of knowledge that the division of the Crinoidea which forms the subject of the present memoir was not known at all to the earlier systematic writers who treated of the Class; neither to J. S. Miller, with whose epoch-making monograph the systematic study of the crinoids as a group began nearly a century ago, nor to Johannes Müller, whose masterly researches upon the anatomy of the Echinoderms 20 years later laid the foundation for future investigations upon their structure. The magnitude of the group as now understood is shown by the size of this treatise; and the progress above alluded to is further exemplified by the manner in which the subject has expanded under my hands.

When I began the study of the Flexibilia after the death of Wachsmuth in 1896, it was part of a more ambitious plan to work up the two groups remaining after the Camerata; and of these it was supposed that the present group would be relatively a minor undertaking. I estimated that 25 plates would contain all the necessary illustrations, and that these with the text would fall readily within the compass of a single volume. All the known material of this group in the museums of the world at that time did not occupy one-fourth of the space that is now required for the specimens of my own collection. Except for a few species, the Flexibilia are the rarest of all the fossil crinoids, some forms being represented by a single specimen, and most of them by only a few. It was my early perception of the inadequacy of material, of the necessity of making further collections, and of examining as far as possible the types and other specimens from all sources, that has in part caused the long delay in the preparation and publication of this work. Far the greater part of the delay, however, has been due to the desultory character of my studies, arising from causes not within my control. The insistent demands of an exacting profession, and the claims of business affairs which absorbed the major portion of my time, caused frequent and often long breaks in the prosecution of the work, the total of which must be measured by years.

These interruptions, however, have not been without their compensating advantages; for during all this time the acquisition of new material, chiefly through the medium of collectors in the field, has been steadily going on, resulting in important additions to our knowledge of this group. And the broader grasp of the subject consequent upon this increase of knowledge has enabled me to place on a firmer basis certain family divisions, which would have been left in an unsatisfactory condition if I had published my results a few years ago.

I think it only fair to observe further, by way of personal allusion, that I have labored under the disadvantage of a lack of practical zoological training, which compels me to limit my treatment of the subject chiefly to the presentation of the facts from a systematic standpoint, without venturing far into the field of evolutionary interpretation. This I prefer to leave to others who are better qualified to undertake it, and it is my hope that this contribution to the sum of knowledge of these organisms may be of some service to those who engage in more general discussions.

It was evident to me at the outset that the plan of restricting the detailed investigation of this group to its American representatives, as was done in the treatise on the Camerata by Wachsmuth and myself, was unsatisfactory. I have therefore endeavored to include in this work all known species of Flexibilia, from whatever areas they may be derived. Such an enlargement of the scope of the research added materially to the labor and difficulty of its prosecution, inasmuch as it became imperative to obtain accurate information in regard to the specimens contained in foreign collections. The most important in relation to the present group of the Crinoidea are those in England, Sweden, Belgium and North Germany.

## Collections

It was my good fortune, thanks to the courtesy of the authorities in charge of them, to whom I am under a heavy obligation, to be able personally to study the material in most of the principal collections of those countries. First among these is that of the British Museum, containing the original collections of Gilbertson, Lord Enniskillen, Sir Philip Egerton, Mr. John Gray and others, including many of the types of Phillips, and specimens studied by Bather in the course of his various investigations; I have enjoyed the advantage of frequent communication and of personal conferences with Dr. Bather during the period of my studies on the Flexibilia, and he has with great generosity turned over to me for description some interesting specimens belonging to this group which he had himself proposed to describe. Other important material was furnished from the rich collection of Wenlock crinoids in the Dudley Museum, and the equally important collection from the same locality made by Mr. Charles Holcroft now belonging to the Museum of Birmingham, as well as from another by Mr. William Madely. These Silurian crinoids from the typical locality at Dudley were supplemented by a very fine series secured by myself from several private collections made in that vicinity during the years when the quarrying operations were most productive. The original collection of the

Austins in the Free Public Museum at Liverpool, containing the types of the species described in their monograph of 1843 to 1849, was placed at my disposal. I also had the privilege of examining an extremely important collection made in recent years from the Upper Carboniferous by Mr. James Wright, Jr., of Kirkcaldy, Scotland, who with the greatest liberality sent me for study at my leisure his entire series of specimens of Flexibilia. From certain other British collections which I was unable to visit I have been supplied with photographs, casts, and in some cases detailed drawings of all the important specimens pertaining to this group; chief among them were those of the Sedgwick Museum at Cambridge, containing the types of various species proposed by Salter with catalogue names, and the Museum of the Geological Survey of Ireland, at Dublin, containing the important types of M'Coy's species.

I also examined the types of De Koninck and Le Hon in the Musée Royal d'Histoire Naturelle in Brussels, in the Muséum d'Histoire Naturelle in Paris, and was furnished with casts of certain specimens of special importance; also the crinoids in the Museum of the University of Bonn, together with the fine private collection of Dr. B. Stürtz, both rich in Middle Devonian species from the Eifel, and Lower Devonian species from the slates of Bundenbach and Gemünden. In addition to these I have had the benefit of a fine series of Eifel crinoids obtained by myself from local collectors at Gerolstein, and also at Prüm by purchase of the collection of Lehrer Kroeffges, who was one of Schultze's collectors prior to 1865. More important than all these, however, in connection with the Eifel crinoid fauna, is the collection of Schultze now at the Museum of Comparative Zoology of Harvard College, containing most of the types of his classic monograph.

To my very great regret I was unable, owing to pressure of business matters during my sojourns in Europe, to visit the great Swedish collections at Stockholm from the Silurian of Gotland, containing the types of Angelin's Iconographia and of Hisinger's earlier descriptions. But through the good offices of my lamented friend, Dr. Gustav Lindström, I was enabled to secure the services of Mr. Georg Liljevall, the accomplished artist and preparator of the Riks Museum, who has through a series of years made for me a careful study of all the Flexibilia material in the Stockholm collections, and has furnished me detailed drawings, not only of all the types of Angelin and Hisinger, but of every other specimen belonging to this group, existing in their time or subsequently acquired, which might throw any light upon the Gotland fauna. Mr. Liljevall is not only an artist of superb technique, but a keen and accurate observer who knows the crinoids of Gotland most thoroughly; and I feel certain that by means of his patient and conscientious studies of this magnificent material I am enabled to give a far more accurate account of it than I could have myself prepared during any such brief visit as I might have made.

Abundant evidence of his care and skill will be found in the plates accompanying this volume, in which every one of Angelin's types belonging to this group has been refigured and his erroneous illustrations corrected, while many new and important figures have been added. I wish to record my extraordinary obligations to Mr. Liljevall for a piece of accurate and truly scientific work such as I think has never been done before under like circumstances. Supplementing the Stockholm material, I was able by purchase and by the employment of collectors on the island to accumulate a very fine series of the Gotland crinoids, including a number of extremely important specimens belonging to this group. The study of all this material has resulted in clearing up several perplexing points left obscure by Angelin.

In America all the collections of museums and individuals have been placed without reserve at my disposal, with liberty to remove such of the material as I desired to my own quarters for study at leisure. It is impossible to express the full measure of my appreciation of this generous assistance, or the sense of obligation which I feel, not only for the facilities thus extended to me, but still more for the extraordinary courtesy and good-will with which they were offered. A brief enumeration of these collections follows:

The facilities of the United States National Museum have at all times been freely accorded in aid of my studies upon the crinoids, especially under the administration of the Hon. Charles D. Walcott, Secretary of the Smithsonian Institution, and of Dr. Richard Rathbun, Assistant Secretary in charge of the National Museum. In 1909, upon being informed of my desire to arrange for a permanent resting place for my collection of fossil echinoderms and library pertaining thereto, which had by that time grown beyond the capacity of the private museum formerly maintained at Burlington, Iowa, Dr. Walcott offered to provide suitable quarters for the collection, as well as for my researches, in the magnificent new building of the National Museum then under construction. Accordingly, in 1911, the transfer was made; a selection of the specimens especially adapted for exhibition was installed in the Hall of Invertebrate Paleontology; the remainder, contained in about one thousand of the usual museum trays, was deposited in the research rooms assigned to me, where for the first time in many years the whole of it became conveniently accessible for study. In these commodious quarters the prosecution of my researches has been facilitated and made pleasant by the unvarying kindness of Dr. George P. Merrill, Curator of the Division of Geology, and Dr. R. S. Bassler, Curator of Paleontology. To Dr. Bassler I am especially indebted, along with many other favors, for valuable assistance to my collectors in the field in the interpretation of the stratigraphy, and for the use of his fine photographic equipment which has been at all times at my disposal, together with what was of still greater value to me, his own personal skill in operating it in special cases. I have also enjoyed the advantage of frequent consultation with Dr. E. O. Ulrich, of the U. S. Geological Survey, whose intimate knowledge of the stratigraphy of the American continent, and great familiarity with the interior Paleozoic areas and their faunas, have been of the greatest service.

Regarding its own fossil crinoid material, the National Museum contains specimens from time to time collected by the United States Geological Survey, including types described by Meek and by C. A. White many years ago. It also has collections made by Dr. Ulrich and by Mr. I. H. Harris in the Cincinnatian and adjacent areas; by Dr. Carl Rominger in the Michigan Devonian; and the extremely important collection of Troost, chiefly from Tennessee, made about the middle of the last century by one of the pioneer paleontologists of this country, and used as the foundation of a monograph of the crinoids of that region prepared by him in 1850, but which remained unpublished until the National Museum brought it out in 1909 under the editorship of Miss Elvira Wood.

Most important of all the museum material is the truly magnificent and unrivaled collection of Recent crinoids, brought together chiefly during the past 10 years, largely through the energetic activities of Mr. Austin Hobart Clark. Beginning with a small nucleus containing some of the material derived from various early dredging expeditions by vessels of the United States Coast Survey, it was in 1907 suddenly enriched by the product of a year's cruise of the United States Bureau of Fisheries' Steamer *Albatross* in the North Pacific, Alaskan, Japanese and Philippine waters, collected by Mr. Clark as acting naturalist, which revealed a surprising and wholly unexpected wealth of crinoidal life in those regions. This was augmented by collections on subsequent cruises, and by some private donations. To these accumulations must now be added extensive material derived from numerous foreign collections, placed in Mr. Clark's hands for description by the institutions and governments owning them, consisting of duplicates which he was permitted to retain as author's honoraria. From this source came 957 specimens, belonging to 121 species, which will be further increased from similar collections still under investigation. The cosmopolitan character of these acquisitions may be judged by the following list of the expeditions and collections from which they have been derived: *Ingolf* (Danish), Greenland and Northwest Atlantic; *Helga* (Irish), West Ireland; Danish expeditions to Siam and to the Danish West Indies; *Investigator* and *Golden Crown* (Indian), Indian Ocean; *Endeavour* (Australian); Western Australian Museum, Perth, and Australian Museum, Sydney; *Siboga* (Dutch), East Indies; Sv. Gad collection from Singapore; Suensson collection from East Asia, Copenhagen; *Gazelle* (German), East Indies and Australia; *Gauss* (German), Antarctic; *Golden Hind* (Japanese), Japan.

All of the specimens so obtained from these widely distributed faunas have been added to the museum collection, thus bringing together, either by way of types or of authentic representative specimens, nearly all the species described by Mr. Clark in his various publications, so that the collection now includes among its 5387 specimens about 350 species from all the oceans, being over 60 per cent of the Recent crinoids known to science. This comprehensive material has formed the basis of Mr. Clark's numerous works on the Recent crinoids, consisting of the first volume of his Monograph of the Existing Crinoids, and 125 other memoirs and papers, including 23 published by foreign authorities. These researches have resulted in the description by the author of 343 new species out of a total of 567 now described, to which will be added upwards of 50 more now under investigation by him; and in the creation of 123 out of the 142 known genera.

As having a special bearing upon my own work it may be noted that there is now contained in this museum collection an assemblage of larval forms of different genera from various areas such as has never been brought together before, some of which have been utilized by me in studies throwing new and important light upon the phylogeny of the fossil forms. From the standpoint which I have constantly maintained, that the fossil crinoids must be studied in connection with their living representatives, the advantage of the free use of such a great collection cannot be overestimated. This has been augmented by the privilege of drawing without limit upon Mr. Clark's vast fund of knowledge of the Recent crinoids, as to which I have been in constant communication with him ever since he began his crinoid studies in 1907. For the opportunity of unrestricted access to, and liberty to use, the specimens of this collection I wish to acknowledge my indebtedness to Dr. Paul Bartsch, Curator of Marine Invertebrates in the National Museum.

At the Museum of Comparative Zoology of Harvard College my status as Associate in Paleontology in former years gave me officially the run of the collections; but the cordial interest in the work manifested by Mr. Alexander Agassiz during his lifetime, and by Mr. Samuel Henshaw, Director of the Museum afterwards, made my studies there doubly enjoyable. Containing as it does the original collections of Wachsmuth and Barris from the Lower Carboniferous of Burlington and vicinity made prior to 1874, including numerous types of species described by Meek and Worthen in the Illinois reports; of Walcott from the New York Trenton; of Dyer from the Cincinnatian; and of Schultze from the Eifel Devonian;—the Harvard material is of first importance in any investigation of the crinoids.

At Yale University Museum there are important collections made by Beecher in the New York Devonian, containing types of species described by Miss Talbot; and by Bradley and Hovey from the Crawfordsville beds of Indiana, including types of some of my own species.

The American Museum at New York contains most of the types of the crinoids described by Hall in the New York Reports; and the State Museum at Albany has nearly all the remainder, as well as the types of Hall's species from the Waverly of Ohio.

The Museum of Cornell University at Ithaca has the types of the species described by Williams, and also one or two of those described by Hall.

The Victoria Memorial Museum of Ottawa, administered by the Geological Survey of Canada, contains the material which served as the basis of E. Billings's important memoirs on the Crinoids and Cystids of Canada, and specimens described by Walter R. Billings; and the University of Toronto possesses a splendid collection of Devonian and Silurian crinoids presented to it by Sir Edmund Walker, including types studied by Parks.

The Walker Museum of the University of Chicago is a rich repository of fine crinoidal material. In addition to the collection of Gurley, containing most of the types of Miller and Gurley's numerous species, and the second collection of James Hall, there are those made by Dr. C. C. Washburn and by Dr. Herrick E. Wilson from the Indiana Silurian; that of Sir William van Horne from the Silurian and Carboniferous of Illinois; that of Mr. F. A. Sampson from the Carboniferous of Missouri; the numerous specimens obtained in recent years by Dr. Stuart Weller in connection with his field work for the Illinois Geological Survey, and the types of the many species described by him from the Silurian of the Chicago area and from various other formations. Dr. Weller's information and advice touching the geological position of several crinoidal beds in southern Illinois have been of the utmost service in the placing of certain species of doubtful horizon described in the early western reports. In this collection are now to be found the long missing types of Owen and Shumard's species described in 1852, rescued from a rubbish barrel at the old David Dale Owen headquarters in New Harmony, Indiana.

The University of Illinois at Champaign possesses the original collection of Professor Worthen, containing the types of Hall's species described in the Iowa Report of 1858; while in the State Museum at Springfield is the abundant material accumulated by the Geological Survey of Illinois under Worthen, including many types described by Meek and Worthen in the Illinois Reports.

The University of Iowa, at Iowa City, has some excellent material collected by Professor Calvin, and also the fine collection of Recent crinoids obtained by Professor Nutting on his remarkable dredging expedition to the West Indies in 1893. In the Davenport Academy of Sciences are some types of species described by Barris; and in the Academy of Science of St. Louis some of the early collections of Shumard and Yandell.

Professor R. R. Rowley at Louisiana, Missouri, has an extensive collection of Missouri crinoids from Carboniferous, Devonian and Silurian rocks, including important types of species described by him. Mr. George K. Greene, of New Albany, Indiana, had the types of species described by Rowley in Mr. Greene's Contributions to Indiana Palaeontology, and since his decease pending the publication of this volume his collection has been acquired by the American Museum. The collection of the late Professor Borden at Borden, formerly New Providence, Indiana, contains specimens obtained by Dr. Knapp at Louisville, and Dr. Harrod at Canton, Indiana.

All the foregoing collections I have carefully examined, and through the courtesy of their owners I have selected from them such specimens as I desired for study and figuring, as already stated.

It must be said, however, I hope without unseemly pretension, that for the elucidation of the group of crinoids under consideration in this work by far the most important and extensive material is that contained in my own personal collection, now deposited in the National Museum. This has come about not only through the acquisition by purchase of many old and typical collections, but because for 20 years I have given close attention to the assembling of specimens pertaining to this group with special reference to these researches. A brief statement of the sources from which the collection is derived will indicate the nature and extent of this material:

ORDOVICIAN:

*Chazyan.* Collections by Wachsmuth, Wetherby, and Braun from the Ottosee formation in Knox and Granger counties, Tennessee.

*Trenton.* The collection of Professor W. F. Pate, of Lebanon, Kentucky, especially rich in crinoids from the Mohawkian area of Woodford and Mercer counties, Kentucky. Collections made for me by Dr. E. Kirk at Kirkfield, Ontario, Canada, containing among other things the material used in my memoir on a Trenton Echinoderm Fauna, published by the Geological Survey of Canada in 1911. Also excellent material from the beds at Ottawa, Canada, obtained through Mr. Walter R. Billings, and from the Black River beds at Minneapolis, Minnesota, and Mineral Point, Wisconsin, collected by Dr. Sardeson and by Mr. Braun.

*Cincinnatian.* The original collection of Mr. J. Kelly O'Neall, of Cincinnati, containing types of several of Hall's species described in the Ohio Reports; many specimens from the Cincinnati area obtained by purchase and exchange; collections made by Braun in the Oswego area, Illinois; and important type and other material in the S. S. Lyon collection.

*Foreign Ordovician.* An important series collected for me by Professor J. J. Jahn, of Brünn in Bohemia, from Étage $d_4$ near Zahoran.

SILURIAN:

*Rochester Shales.* The extensive collection of Dr. E. N. S. Ringueberg at Lockport, New York, containing the types of his species, and material accumulated during many years of careful collecting. Still larger collections made by Mr. Braun for me at Lockport, through extensive quarrying in the productive layers during the seasons of 1910, 1911 and 1914. Collections in the Osgood area of Indiana by Beachler.

*Laurel* and *Waldron.* Collections at St. Paul, Indiana, by Beachler in 1887; Braun in 1911, and Wilson in 1915, 1916 and 1917; also specimens from Dr. Moses Elrod at Hartsville, and from Dr. C. C. Washburn, of Waldron, prior to the acquisition of his collection by the University of Chicago. Collections made by Pate, Braun and Bassler in the Waldron beds of Tennessee. The collection of John F. Hammell, of Madison, Indiana, including that of A. C.

Benedict; both rich in Osgood, Laurel and Waldron echinoderms, and containing many types of species from the Cincinnatian, Niagaran, and Hamilton of Indiana.

*Racine dolomites.* A good representative series from the Chicago area, by exchange; and from equivalent horizons in New York and Ohio collected by Braun.

*Brownsport* to *Louisville.* Collections made by Wachsmuth during several seasons in Tennessee along the Tennessee River; collections of great importance made by Professor Pate for me in Decatur and adjoining counties, Tennessee, in 1906 and 1907, chiefly by extensive quarrying operations. These yielded an extraordinary series of well-preserved crinoids which includes many new forms, and representatives of European genera hitherto unknown in America; they will form the subject of a monograph now in preparation, for which drawings are already made to fill at least 25 plates. A small but choice collection made by Mrs. J. M. Milligan, of Jacksonville, Illinois, in Decatur County, Tennessee, containing the types of several species from the Brownsport horizon described by Miller and Gurley. With the S. S. Lyon collection much valuable material from that horizon was obtained, and Braun collected there successfully in 1910.

*Wenlock.* From Dudley, England; a good local collection purchased at Dudley in 1887, and many additional specimens obtained through exchange, and occasional purchase from dealers; the material thus secured being especially rich in good specimens of the Flexibilia, in which from this locality it is more complete than any other outside of the British Museum. From Gotland, Sweden; collections made for me in 1894 and 1895 by Professor G. Klintberg, and in 1906 by Mr. A. Florin, besides continual additions through purchases from dealers; this material also is strong in rare species of Flexibilia.

For 20 years I had a standing arrangement with the well-known fossil dealers, Krantz in Bonn and Damon in Weymouth, to inform me of every new acquisition of crinoids and to send me for examination such as I might designate. Much valuable material was from time to time obtained in this way, especially from the English and Swedish Silurian, the Devonian of the Eifel, and the Russian Carboniferous.

DEVONIAN:

*Helderbergian* and *Oriskany.* The collection of Frank Hartley, of Cumberland, Maryland, acquired in 1908, containing the types of species described by Schuchert; it is rich in echinoderms from the beds at Keyser, West Virginia, and contains the finest lot of *Edriocrinus* and other forms (some undescribed) from the Oriskany ever obtained. Also collections made by Braun in 1907 at Cumberland; in the Linden beds of Tennessee; and in 1912 at Cape Girardeau, Missouri, in the equivalent Bailey limestone, producing the extraordinary specimens of *Scyphocrinus elegans,* described in my memoir of 1917. Collections made by Mr. Pate in 1914 and 1915 in the Linden beds of Hardin and adjacent counties in Tennessee, yielding the other specimens of *Scyphocrinus* and its bulbous root *Camarocrinus* forming the further basis of the memoir upon those forms above mentioned. Good specimens of *Scyphocrinus* were also obtained from the typical locality at Karlstein in Bohemia.

*Onondaga* and *Hamilton.* The original collection of Col. Sydney S. Lyon, and that subsequently made by his son, Mr. Victor W. Lyon, of Jeffersonville, Indiana, containing the types of nearly all the species of Lyon, and of Lyon and Casseday, and some of Wachsmuth and Springer, chiefly from the Onondaga and Hamilton rocks of the Louisville, Kentucky, and Clark County, Indiana, areas; and also important material from the Knobstone, Keokuk and Kaskaskia beds of Indiana and Kentucky. Colonel Lyon had prepared drawings for the species published by him mostly without illustration, intending to republish them with others undescribed; but his project was interrupted by the Civil War of 1861 to '65, through which he served as a gallant officer in the Federal army. His drawings passed into my hands with his collection, and they bear ample testimony to his keenness of observation and zeal in the study of the crinoids. The younger Lyon was also an ardent collector for many years; and these two collections furnish the best exposition of the crinoid faunas of that region made up to their time. Another very fine collection limited to the beds at and around Louisville was made in the early years by Dr. J. Knapp, and afterwards passed into the hands of Professor W. W. Borden, of Borden, Indiana; it contained type and other specimens of much importance which Professor Borden with extraordinary generosity presented to me, and some of which were described in my memoir on American Fossil Crinoids, in 1911. Since 1896 nearly all the crinoids found in the Louisville area by the veteran and indefatigable collector, George K. Greene, of New Albany, Indiana, have been submitted to me for inspection and for the purchase of such as I desired; continual purchases were made from him, largely with a view to a revision of the genera *Dolatocrinus* and *Hadrocrinus,* which were not adequately treated in the North American Crinoidea Camerata for want of proper material. This has now been supplied, and numerous drawings for the proposed paper have been made. Mr. Greene lived in the midst of the crinoidal exposures at and near the Falls of the Ohio, and could watch them at all stages of water; scarcely a season passed without a good haul being made. Among the acquisitions from him is considerable undescribed material. Collections made by Kirk in the Onondaga of New York in 1906, and by Braun in 1910, and a fine series from the Onondaga of Columbus, Ohio, given to me by Rev. H. Hertzer, whose collections of fossil fishes have enriched the paleontology of that state. The collection of Rev. W. H. Barris from the Hamilton strata near Davenport, Iowa, but especially in the Alpena region of northern Michigan—the product of several summer vacations spent in the field by that ardent paleontologist; it contains types of species described by Wachsmuth and Barris and by Barris alone, and a large number of fine specimens of other species, including some new. This is supplemented by extensive collections afterwards made for me in the same region by Kirk with better facilities; and also by some specimens from the Tiffany collection at Davenport, Iowa. Collections made for me in the Hamilton of Callaway County, Missouri, by Mr. D. K. Greger, of Fulton, Missouri; in the Hamilton and Portage of New York near Moscow and Naples by Kirk in 1908; in the Chemung at Belmont, N. Y., by Braun in 1909.

*European; Lower Devonian.* Slates of Gemünden and Bundenbach in northern Germany; a complete series from Dr. B. Stürtz at Bonn, and subsequent purchases.

*Eifelian.* Good collections obtained by me during a tour of the Eifel Mountains in 1887 from local collectors, including that of Kroeffges at Prüm; and numerous purchases from collectors and dealers in Gerolstein and Bonn at frequent intervals since—all resulting in a very complete series of the Eifel crinoids, and exceptional specimens of some species. A good series of the species from equivalent strata in southern France and Spain was obtained by exchanges.

LOWER CARBONIFEROUS:

*Waverly; Kinderhook; Choteau.* Collection made for me in the Ohio Waverly at Richfield, Ohio, by Beachler in 1888. Large collections from the so-called Kinderhook horizon made during several visits by Wachsmuth and myself at Le Grand, Iowa—one of the remarkable localities for finely preserved crinoids and blastoids—and by purchase from local collectors. By arrangement with the owners of the quarry we were present when the crinoid layer was exposed and taken out under our direction, thus enabling us to obtain great numbers of specimens in perfect condition. From the equivalent of the Choteau at Lake Valley, southern New Mexico, a large collection was made by myself during three visits, embracing many species common in the rocks at Burlington.

*Lower* and *Upper Burlington.* The typical locality for these horizons is at Burlington, Iowa, which has been classic ground for crinoid collectors ever since the descriptions by Owen and Shumard in 1852; the residence of Wachsmuth for 35 years, and of myself for five, and the seat of our joint paleontological investigations from 1878 forward. No other locality compares with it for abundance, preservation and variety of fossil echinoderms, the number of described species of crinoids and blastoids amounting to 334. The exposures are very extensive; quarries in former years were numerous, and transient collectors could generally find weathered specimens of the more usual species. But it was the local collectors, who understood the strata and could watch the quarries when rich layers were opened, or quarry for themselves in favorable spots, by whom were found the bulk of well-preserved specimens which made the locality famous; many of the fossils with their light color and delicate markings appeared as if freshly dredged from the sea. In this kind of truly scientific collecting Wachsmuth was past master, and he took great pride in it to the last, insisting that to understand fossils best one must know them in the rocks. His knowledge of strata was almost uncanny; so that he could often tell when a rich layer was about to be uncovered in a quarry and make arrangements for securing its contents. It was the current belief among the quarrymen that he possessed a sort of second sight for good fossils that was not shared by other men. There were other good collectors also, and a number of fine individual collections were from time to time accumulated, most of which eventually passed into my hands. During the last 10 years of his life, in order to escape the trying climate of early spring, Wachsmuth went to the south every February accompanied by his devoted wife, who was an ardent collector also, collecting at many localities in Kentucky and Tennessee, but principally in the vicinity of Huntsville, Alabama. He thus made immense collections in the later formations of the Lower Carboniferous—Keokuk, St. Louis and Kaskaskia—many of them by quarrying after tracing the crinoids to their layers, by which means he obtained unweathered specimens in a condition of perfection that no one had seen before.

Of the earlier collections at Burlington, three went to the Museum of Comparative Zoology at Harvard, viz., those of B. J. Hall, W. H. Barris, and Wachsmuth, all made prior to 1874, and containing many types of species described by James Hall, and by Meek and Worthen. With the exception of these, and occasional small lots obtained by visitors, and scattered through the museums of the world; one small but very choice series secured by the British Museum; and a small collection by the Field Museum, Chicago;—the present collection contains substantially all the fossil echinoderms that have been collected at Burlington and vicinity during the past 50 years. It is derived from the following sources: My own personal collections made from 1867 to 1872; that of Wachsmuth and of Wachsmuth and myself jointly after 1874, including the product of frequent expeditions to other Burlington and Keokuk localities in Iowa, Illinois, Missouri and Kentucky, and continual purchases from quarrymen and small local collectors who usually brought their finds to Wachsmuth for inspection; the original collection of Dr. Charles A. White made before 1866, containing types of species described by him and by James Hall, disposed of to the University of Michigan and subsequently acquired by me through exchange; the early collections of Dr. Otto Thieme, Enoch May, J. W. Giles, James Love, H. Griffith, S. Bittner, and an especially fine one of later years of Mr. J. O. Beebe; collections made by myself at intervals from 1896 to 1911, especially through extensive quarrying at various points by a regular collector during several years, resulting in important new acquisitions.

From the so-called Knobstone formation, equivalent in part to the Lower Burlington, important collections were made in southern Indiana, the Knobs of Kentucky, and at White's Creek Springs, Tennessee, by Wachsmuth, and afterward extensively by Braun; to which must be added two choice sets of the crinoids of that formation given to me by Dr. Karl Rominger, of Michigan, and Rev. H. Hertzer, of Ohio, both containing specimens of much importance especially in the Flexibilia.

*Foreign equivalents.* From the approximate foreign equivalent, the Mountain limestone of Belgium and Britain: The collection of Mr. Ad. Piret at Tournai, acquired in 1888; and all the important crinoid material collected by him for the next 20 years, including some especially valuable specimens for the study of this group. A good series embracing most of the known species from the British rocks in Waterford County, Ireland, and in Yorkshire, England.

*Keokuk; western area.* The original collection of Lisbon A. Cox, of the city of Keokuk, Iowa, being the result of 30 years steady collecting in the western Keokuk limestone of the Mississippi River area in Iowa, Illinois and Missouri—by far the most complete series of the crinoids of that region ever brought together. It contains the types of a large number of species described by Worthen in Volume VII of the Illinois Geological Survey Reports, and by Wachsmuth and Springer in the Camerata monograph. Mr. Cox was in the field during the years of excavation of the canal around the rapids of the Mississippi River at Keokuk, and profited greatly by the opportunities thus afforded; and he also did some quarrying on his own account in especially favorable spots. Two other small local collections purchased, and the product of occasional expeditions by Wachsmuth and myself into the western Keokuk area, supplement the material contained in the Cox collection with important additions.

*Keokuk shales and limestones east of the Illinois uplift; chiefly in Montgomery County, Indiana.* Next to Burlington the most famous crinoid locality in America is Crawfordsville, Indiana, containing the largest colony of Paleozoic crinoids ever found, specimens from which are to be seen in all museums. The number of species does not exceed 40, but the specimens occur in great profusion, and at certain spots in excellent preservation as to arms and stems, but not as to fine structures—being injured in this respect by the presence of iron pyrites. A large collection made by M. Zeller was purchased in 1880; subsequently I acquired the ground in which the best part of the deposit was situated, where I carried on large quarrying operations in 1887 under Charles S. Beachler, assisted by the veteran Indiana collector, O. W. Corey, who had worked the beds extensively in early years;[1] and to a still greater extent under Mr. Braun in 1906. Both of these operations yielded finely preserved specimens in great quantity.

A still more important locality, if not so famous, in the same area but slightly lower, was on Indian Creek about 12 miles from Crawfordsville. It was discovered by Mr. Beachler while collecting for me in 1888, being a small colony which produced several thousand specimens of about 20 species in a state of preservation nowhere surpassed, especially as to structural details. The remarkable preparations showing the tegmen of *Onychocrinus* figured in this work came from there. In 1907 Mr. Braun uncovered another colony a short distance from the last, from which a large amount of extraordinary material was obtained. Another prolific locality at an equivalent horizon was near Canton, in Washington County, southern Indiana, where a fine collection from the principal colony was made by Wachsmuth during one of his annual trips, and by Braun, in addition to important typical material contained in the Lyon collection.

*Warsaw.* From the western area an excellent assortment from these beds was collected at Boonville, Missouri, by Beachler, and still more material was obtained in the Hambach collection. The Salem beds in the Spergen Hill region were carefully worked by Wachsmuth, Beachler, and in later years by Braun, yielding a complete representation of their fauna.

*St. Louis.* The original collection of Dr. G. Hambach, of St. Louis, acquired by me in 1907, containing the types of his published investigations on the Blastoids, and a vast quantity of other blastoid, crinoid, and echinoid material, especially from the St. Louis, Kaskaskia, Warsaw and Keokuk beds, and also from the Choteau and Lower Burlington beds of southwestern Missouri, and the Upper Carboniferous at Kansas City.

*Kaskaskia.* Wachsmuth's years of collecting at Huntsville, Alabama, yielded great numbers of crinoids and blastoids from this horizon, as also did Pate's collection from western Kentucky. Wachsmuth rediscovered Wetherby's famous locality in Pulaski County, Kentucky, which yielded wonderfully preserved specimens of this formation, and I also obtained an extremely fine series of them from a local collector. Braun visited this locality in recent years with good results, although the great wealth of former times was not again disclosed. The S. S. Lyon collection contained excellent material from the typical locality at Grayson

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[1] 16th Report State Geologist, Indiana, 1889, p. 64.

Springs, Kentucky. In Monroe and Randolph counties, Illinois, Braun in 1913, by careful collecting and by quarrying in one locality, obtained a very fine lot of well-preserved specimens of this formation; while the Hambach collection contains the fruits of many years' annual expeditions into that region.

*Foreign equivalents.* Russian; from the Bergkalk at Moscow, a complete series obtained from Professor Trautschold, including good specimens of all his species, supplemented by others secured since that time by purchase from dealers. British; from the Hurlet limestone of the Scotch Carboniferous, a fauna remarkably similar to the American Kaskaskia, a good collection obtained by exchange.

*Upper Carboniferous.* Straggling specimens from the Lower Coal Measures of Kansas and Illinois. From the upper beds and Permo-Carboniferous of Missouri, Kansas, and New Mexico. Especially two collections by local collectors from the great find of well-preserved specimens at Kansas City, and a considerable quantity of the same material in the Hambach collection.

MESOZOIC:

Very complete series from the Muschelkalk of the German Trias—*Encrinus* and allied forms; from the Liassic of Lyme-Regis, England, and the Holzmaden area in Germany—*Pentacrinus,* etc.; the Middle Jurassic of England and Northern France—*Apiocrinus,* etc.; Upper Jurassic of France, Germany and America—*Isocrinus,* etc.; Cretaceous of England—*Marsupites, Bourgueticrinus,* etc.; and of America, *Uintacrinus*—the extensive material used in studies for my memoir of 1901 on that genus, except most of the figured specimens which are at the Museum of Comparative Zoology.

RECENT:

A small but useful series of comatulids and stalked crinoids necessary for the study of the fossils, accumulated prior to the removal of my collection to Washington, containing some extremely rare forms, such as *Holopus.*

Speaking of the Flexibilia alone, the collection contains good specimens of 142 species out of the total of 176, or 80 per cent of all the recognized forms.

## COLLECTORS

During the years in which the above-mentioned material was being accumulated I was fortunate in obtaining the services of several able and zealous collectors. The first was Mr. Charles S. Beachler, of Crawfordsville, Indiana, a graduate of the Wabash College of that place, who began his field work under my direction in 1887, and continued for about four years. During this time he quarried the famous Crawfordsville beds; discovered in the same county the more important locality on Indian Creek, which goes by his name among the fossil hunters, and spent another season working it; made collections in two other Keokuk localities discovered by him in that region; quarried in the Waldron beds at Conn's Creek; collected carefully in the Laurel exposures at St. Paul; made two trips among the different localities in southern Indiana and Kentucky, and also one to Boonville, Missouri. He had a good knowledge of the geology of the Indiana Carboniferous formations, and published several papers in relation to them. Mr. Handel T. Martin, now Curator of Paleontology in the University of Kansas at Lawrence, assisted me in making my extensive *Uintacrinus* collections in the Cretaceous of western Kansas, and afterwards collected for me in the Upper Carboniferous of eastern Kansas. Dr. Edwin Kirk, now a member of the staff of the United States Geological Survey, made for me an extremely valuable collection in the Trenton beds at Kirkfield, Ontario; three others in the Onondaga, Hamilton, and Portage rocks of New York; and still another during a season's work in the Hamilton of northern Michigan.

The veteran collector, Frederick Braun, now of Brooklyn, New York,[1] whose specimens from Crawfordsville and Cincinnati in former years found their way to all the museums of Europe, carried on field work for me from 1906 to 1914, collecting echinoderms exclusively. He has a keen eye for fossils, and is a master in recovering them from the rocks when a productive bed is located; in this kind of work his patience, perseverance and resourcefulness are without limit. During the years mentioned he carried on large quarrying operations at Crawfordsville, Indiana, sending in 115 boxes of fossil crinoids as the result of a season's work, in which he exhausted the locality for any systematic collecting; another season he worked in a similar way a rich bed found by him on Indian Creek, from which he filled 25 boxes; he quarried during three seasons in the Rochester shales at Lockport, New York, with most important results in the way of finely preserved specimens such as had not been obtained before at that celebrated locality; another season's work was done at Cape Girardeau, Missouri, resulting in the securing of the extraordinary material described in my memoir on the genus *Scyphocrinus*. In addition to these long campaigns he made several more general trips, on which he collected in the Onondaga and Hamilton of New York, the Niagaran of St. Paul, Indiana, and of Decatur County, Tennessee; the Ordovician of Knox and Granger counties, Tennessee, and of Mercer and Woodford counties, Kentucky; the Linden of Perry and Benton counties, and the Niagaran near Nashville, Tennessee; the Knobstone of White's Creek, Tennessee, and of the Knobs of Kentucky and southern Indiana; the Kaskaskia of Monroe and Randolph counties, Illinois; and the Ordovician of the Oswego region in Illinois, and of southern Wisconsin.

In 1905 I purchased the large collection made by Professor W. F. Pate, of Lebanon, Kentucky, chiefly in that state and Tennessee. He was then on the staff of the Kentucky Geological Survey as Associate Geologist during the summers, but through the courtesy of the Director, Dr. Charles J. Norwood, I was enabled to secure his services for a collecting campaign in the Niagaran of Decatur County, Tennessee, which had been a favorite collecting ground for paleontologists since the times of Troost and Roemer. This he prosecuted during the two following seasons, tracing the fossils to their strata in place, and quarrying, which resulted in securing more finely preserved specimens than had been found by all previous collectors during 50 years, forming an assemblage of crinoids which will take rank with the great collections from the equivalent horizon in the Island of Gotland, and which exhibits in some respects a remarkable parallelism with the Gotland fauna. Afterward Mr. Pate spent a considerable part of two more seasons in the Linden beds of Hardin and adjacent counties in Tennessee, with extraordinary results in the way of new material to which my memoir on the genus *Scyphocrinus* bears witness. Mr. Pate knows the geology of Kentucky and Tennessee most intimately, and when in the field collects with amazing energy, and with an intimate knowledge of the stratigraphy.

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[1] Deceased, December, 1918.

During the past three seasons my assistant, Dr. Herrick E. Wilson, has made important collections in the Laurel limestone at St. Paul, Indiana, and vicinity, the crinoid fauna of which bears a striking resemblance to that of a part of the Wenlock of Gotland. Dr. Wilson has also made the microscopic studies and the drawings upon the remarkable series of comatulid larvae described and figured in this work.

## ILLUSTRATIONS

I have been peculiarly favored in the preparation of the drawings for the accompanying plates by having the services of two of the most skillful living artists in this line of work. Mr. Liljevall's share in their execution has already been stated. Mr. Kenneth M. Chapman, now of Santa Fé, New Mexico, began making drawings for me in 1900, and has continued to do so ever since. He was then without experience in that class of work; but his technical skill, fine artistic sense, and keen scientific observation of details enabled him to keep pace with my requirements until he became the master to whose preëminence the 75 beautiful plates of this work, as well as the numerous others in previous publications, bear convincing testimony. His unflagging interest in the preparation of these volumes has made our association one of continual pleasure. Mr. Chapman in addition to the pencil wields a skillful brush, as his canvasses in oil show, and his original studies upon the evolution of Decorative Art have made him one of the leading authorities in that branch of archaeological research.

Mrs. Edith Ricker, of Burlington, Iowa, made some drawings for this work at its beginning, and the fine figure 3 on Plate LXXII stands as proof of her skill. I am also indebted to Professor Maurice Ricker for helpful assistance in photography at that time.

All of my plate figures, except the drawings of comatulid larvae, are made from a photographic basis, but they are not in any sense mere retouched photographs. A very light print is made upon a paper which will take water color, giving the outline and sutural details which formerly constituted the drudgery of the artist; then the picture is worked out with India ink under a low power magnifier, every part being carefully gone over with the brush. Thus scientific accuracy and artistic effect are combined.

The adequate reproduction of the work of such artists is no simple matter, and calls for a degree of care and skill far beyond that of the ordinary commercial printing. It has been accomplished by the Heliotype Company of Boston in a manner that is worthy of the drawings. No pains have been spared to insure the most perfect effects, and it is to the constant attention and vigilance of the company's manager, Mr. W. C. Ramsay, that the admirable results are especially due.

## Acknowledgments

One other acknowledgment remains, not so easy to fittingly express, and that is in relation to Mrs. Bernhardina Wachsmuth, widow of my old friend and associate, Charles Wachsmuth. It is rendered doubly difficult by the fact that the demise of this venerable woman, pending the publication of these lines, compels me to substitute words of affectionate remembrance for those of grateful recognition. After the death of Wachsmuth in 1896 I took over the collection and library which had been accumulated by us together, and thereafter maintained them in the private museum which we had constructed for their security, until I transferred them to the National Museum in 1911. During that period of 15 years, although my residence and business affairs were in New Mexico, I continued my scientific researches at such intervals as my time and other occupations would permit in the little museum in the beautiful city of Burlington, Iowa. The manifold kindnesses, the solicitude for my personal comfort, and the intelligent interest in my work which were at all times exhibited by Mrs. Wachsmuth, could not be adequately characterized by the ordinary expressions of gratitude.

But I wish to here record my appreciation of one of the finest characters I have ever known. She was her husband's untiring companion and helpmeet through all his long years of study and of battling for health, not only in a material way, but intellectually. While without a technical knowledge of geology and paleontology, she was always an intense lover of nature, and a keen observer as well; so she became an ardent and skillful collector, and for the last 20 years of his life accompanied Wachsmuth in all his travels and collecting journeys, tramping cheerfully over mountains and searching among glades and outcrops with an energy that never flagged. Many splendid specimens that enrich this great collection were of her finding. She not only rejoiced in their discovery with the zest of the successful collector, but apprehended their scientific importance as contributions to the problems that were under investigation. The same intellectual interest was maintained toward my own researches, manifested by sympathy and coöperation limited only by her opportunities. To all this must be added an endless list of unostentatious charities, of good deeds to others who were in want, to many of whom her words of kindly cheer were boons no less valued than the comforts which her hands provided. Thus, in the final reckoning, she had accomplished her life's ambition,—" to do her part."

Finally, to the memory of the great Naturalist and Teacher, Louis Agassiz, to whose encouragement and inspiration I owe the continuance of my scientific studies parallel with a business career, I offer the homage of one who has found in them, as he foretold, a resource in later years beyond all price.

Along with those already mentioned, I am indebted to many other persons and institutions for courtesies and assistance in various ways, which I regret that the limits of an introduction prevent me from specifying in detail. I wish to express my deep gratitude for all the favors thus enjoyed; the pleasure of their acknowledgment is marred by the fact that in the long interval that has ensued some of these friends have paid the debt of Time. The following list is intended to include them all:

Mr. Alexander Agassiz, Cambridge, Mass.; American Museum of Natural History, New York; Dr. G. W. Austin, Wilmington, Ohio; Rev. W. H. Barris, Davenport, Iowa; Dr. Paul Bartsch, U. S. National Museum; Dr. R. S. Bassler, U. S. National Museum; Dr. F. A. Bather, British Museum; Mr. Charles S. Beachler, Crawfordsville, Indiana; Mr. J. O. Beebe, Burlington, Iowa; Mr. Walter R. Billings, Ottawa, Canada; Professor W. W. Borden, Borden, Indiana; Professor M. Boule, Muséum d'Histoire Naturelle, Paris; Mr. Frederick Braun, Brooklyn, N. Y.; Professor Samuel Calvin, Iowa City, Iowa; Geological Survey of Canada, Ottawa; Dr. E. C. Case, Ann Arbor, Michigan; Mr. Kenneth M. Chapman, Santa Fé, New Mexico; Walker Museum, University of Chicago; Mr. Austin Hobart Clark, U. S. National Museum; Dr. John M. Clarke, Albany, N. Y.; Dr. William B. Clark, Baltimore, Md.; Dr. C. H. Crantz, Illinois State Museum; Dr. A. R. Crook, Illinois State Museum; Mr. Robert Damon, Weymouth, England; Academy of Sciences, Davenport, Iowa; Professor S. Dollo, Musée d'Histoire Naturelle, Brussels, Belgium; Science and Art Museum, Dublin, Ireland; Dr. Charles R. Eastman, Pittsburg, Pa.; Dr. August F. Foerste, Dayton, Ohio; Professor F. M. Fultz, Burlington, Iowa; Dr. George H. Girty, U. S. Geological Survey; Professor L. C. Glenn, Nashville, Tennessee; Dr. A. W. Grabau, Columbia University, N. Y.; Mr. George K. Greene, New Albany, Indiana; Mr. D. K. Greger, Fulton, Missouri; Dr. J. Walter Gregory, Glasgow, Scotland; Dr. G. Hambach, St. Louis, Missouri; Mr. Samuel Henshaw, Cambridge, Mass.; Rev. H. Hertzer, Marietta, Ohio; Mr. Charles Holcroft, Dudley, England; Dr. G. Holm, Riks Museum, Stockholm; Dr. E. O. Hovey, American Museum of National History, N. Y.; Dr. G. H. Hudson, Plattsburg, N. Y.; Illinois

State Museum, Springfield, Ill.; University of Illinois; University of Iowa; Dr. Jaraslaw J. Jahn, Brünn, Bohemia; Dr. Robert T. Jackson, Cambridge, Mass.; Dr. Charles R. Keyes, Des Moines, Iowa; Dr. E. M. Kindle, Ottawa, Canada; Dr. Edwin Kirk, U. S. Geological Survey; Dr. F. Krantz, Bonn, Germany; Dr. L. M. Lambe, Ottawa, Canada; Mr. Georg Liljevall, Stockholm, Sweden; Dr. G. Lindström, Riks Museum, Stockholm; Liverpool Public Museum; Mr. Victor W. Lyon, Jeffersonville, Indiana; Mr. William Madeley, Dudley, England; Mr. Handel T. Martin, Lawrence, Kansas; Dr. George P. Merrill, U. S. National Museum; University of Michigan; Mrs. J. M. Milligan, Jacksonville, Illinois; Dr. G. A. F. Molengraaff, Delft, Holland; Dr. Theodor Mortensen, Copenhagen; Museum of Comparative Zoology, Harvard College; Musée d'Histoire Naturelle, Brussels; New York State Museum, Albany, N. Y.; Professor C. C. Nutting, Iowa City, Iowa; Muséum d'Histoire Naturelle, Paris; Dr. W. A. Parks, Toronto, Canada; Professor W. F. Pate, Lebanon, Kentucky; Dr. Alexander Pavlow, Moscow, Russia; Dr. J. Perner, Prague, Bohemia; M. Ad. Piret, Tournai, Belgium; Dr. Richard Rathbun, U. S. National Museum; Dr. Percy E. Raymond, Cambridge, Mass.; Mrs. Edith Ricker, Des Moines, Iowa; Professor Maurice Ricker, Des Moines, Iowa; Riks Museum, Stockholm; Dr. E. N. S. Ringueberg, Lockport, N. Y.; Professor C. R. Rolfe, Champaign, Illinois; Dr. Carl Rominger, Ann Arbor, Michigan; Professor R. R. Rowley, Louisiana, Missouri; Professor J. W. Safford, Nashville, Tennessee; Professor F. W. Sardeson, Minneapolis, Minn.; Dr. T. E. Savage, Urbana, Illinois; Dr. R. F. Scharff, Dublin, Ireland; Professor C. Schleuter, Bonn, Germany; Dr. Charles Schuchert, New Haven, Conn.; Dr. A. W. Slocum, Chicago, Ill.; Dr. T. W. Stanton, U. S. Geological Survey; Mr. Charles S. Sternberg, Lawrence, Kansas; Academy of Science, St. Louis, Mo.; Dr. B. Stürtz, Bonn, Germany; Mr. E. E. Teller, Milwaukee, Wis.; Professor H. Trautschold, Breslau, Germany; Dr. E. O. Ulrich, U. S. Geological Survey; United States Geological Survey; Victoria Memorial Museum; Mrs. Bernhardina Wachsmuth; Hon. Charles D. Walcott, Secretary Smithsonian Institution; Sir Edmund Walker, Toronto, Canada; Dr. Stuart Weller, Walker Museum, Chicago; Professor A. G. Wetherby, Cincinnati, Ohio; Dr. J. F. Whiteaves, Ottawa, Canada; Professor R. P. Whitfield, American Museum of Natural History; Professor Henry S. Williams, Cornell University; Dr. S. W. Williston, Walker Museum, Chicago; Dr. Herrick E. Wilson, U. S. National Museum; Dr. Henry Woods, Sedgwick Museum, Cambridge, England; Dr. Henry Woodward, British Museum; Dr. A. Smith Woodward, British Museum; Mr. James Wright, Jr., Kirkcaldy, Scotland; Yale University Museum; Miss Winifred Goldring, Albany, New York; Miss Mary J. Klem, St. Louis, Missouri.

## TERMINOLOGY

The terms employed in this work differ in some particulars from those used by Wachsmuth and Springer in the Crinoidea Camerata memoir. The difference is chiefly in regard to the plates of the brachial series succeeding the radials. For these I have heretofore adopted and shall continue to use the nomenclature and symbols proposed by Bather in Lankester's Treatise on Zoology, Pt. III, p. 143, and previous papers, as being the most philosophical and accurate, and also the logical consequence of our own researches. This conclusion was stated in my memoir on *Uintacrinus*,[1] and I will restate the reasons for it. When in 1881 and 1885[2] we showed that the arms fundamentally begin with the second plate of the ray—*i. e.*, that all plates of the ray above the radial circlet, whether free or not, are brachials—it logically followed that they ought to be designated according to their numerical succession; and we in fact proposed to use the terms "primary," "secondary" and "tertiary" brachials, etc. Upon conference with P. H. Carpenter, who thought those terms too long and cumbrous, we agreed to adhere to the Müllerian "costals," "distichals" and "palmars," as proposed by him.[3] In the Camerata monograph[4] we retained, in an explanatory sense, the alternative terms "primary brachials," "secondary brachials," "tertiary brachials," followed by "brachials of the fourth order," and so on, and employed for them the symbols I, II, III, IV, etc. Bather's invention of the terms "primibrachs," "secundibrachs," etc., and the other terms naturally accompanying them, with their convenient symbols, was a solution of the difficulty, and furnished a terminology for these parts consistent, convenient in use, and easily remembered; and I have employed them ever since, not without, however, an occasional lingering regret for the strong and terse designations of Müller.

Some of the innovations agreed upon by the authors above cited are of questionable advantage. This is notably the case with the old familiar terms "interradials" and "interbrachials," the former meaning plates between the rays, and the latter plates between their divisions. In order to make the descriptive term conform to the current morphological concept (it having been decided that all plates of the ray above the radial circlet belong fundamentally to the arms and are therefore all "brachials"), the term "interbrachials" was shifted so as to apply to that portion of the plates between the rays which are above the radial circlet. This leaves no appropriate or special term for those plates between the rays which lie within the radial circlet, like the first plate in the Rhodocrinidae; this must therefore be included within the general term "interradials," while new and ponderous terms (intersecundibrachs, etc.) must be provided for plates between the ray divisions. This is confusing and wholly unnecessary, the former use of the terms being self-explanatory. While adhering to the term "interbrachial" with the symbol iBr, as now generally employed, I shall reserve the liberty to use the term "interradials" freely in discussion to describe all plates dorsally situated between the rays, whether in the zone of the radials or above. For those in the tegmen the term "interambulacrals" is sufficient.

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[1] Mem. Mus. Comp. Zoology, Harvard, vol. 25, no. 1, 1901, p. 41.

[2] Revision of the Palaeocrinoidea, pt. 2, p. 10; *ibid*, pt. 3, p. 12.

[3] Carpenter, P. H., Ann. and Mag. Nat. Hist. (6), vol. 6, 1890, pp. 11-18; Wachsmuth and Springer, Proc. Acad. Nat. Sci., Philadelphia, vol. 42, Oct., 1890, pp. 374-375.

[4] Mem. Mus. Comp. Zoology, Harvard, vol. 20, 1897, pp. 73-75.

For encyclopedic collections and definitions of terms employed in connection with the Crinoidea, I refer to Bather's chapters in the Lankester Zoology, and to Clark's Monograph of the Existing Crinoids,[1] the first volume of which appeared in 1915. For the purposes of the present work the following list, largely adopted from the Camerata monograph, is deemed adequate:

### Explanation of Terms

*Column* or *stem.* The jointed appendage attached to the dorsal end of the calyx. It is composed of segments or ossicles called *columnals,* which are either *nodals* (cirrus-bearing) or *internodals* (interpolated segments). The longitudinal canal running through the center of the stem into the calyx is the *axial canal.* When speaking of the form of the stem the transverse section is meant. The top columnal is called the *proximale.*

*Arms.* Jointed appendages toward the ventral pole of the calyx, formed by the outward extension in a radial direction of apposed projections of the dorsal wall and ventral perisome given off at the line of union between these two structures. They may be either simple or branching; composed of one series of brachials (*uniserial*), or of two interlocking series (*biserial*); if they branch by substantially equal bifurcations they are called *dichotomous,* if unequally by lateral *ramules,* which may branch again, usually separated by one or more brachials,—*heterotomous.* Both arms and ramules may be fringed with still smaller appendages called *pinnules* given off at alternate sides from every successive brachial, or sometimes from both sides of each; the component ossicles of the pinnules are called *pinnulars.* Neither simple nor biserial arms, nor pinnules, are known in the Flexibilia.

*Crown.* The crinoid minus the column.

*Calyx.* The crinoid minus the column and free arms.

*Dorsal cup.* All parts of the calyx below the origin of the free arms.

*Tegmen.* That part of the calyx lying above the origin of the free arms, being the integument covering the viscera; it embraces the disk-ambulacra, the mouth, and usually the anus; and it is synonymous with the terms *disk, ventral disk, vault, dome, summit.*

*Base.* That part of the dorsal cup lying next to the column. It may be composed of one ring of plates (*monocyclic*), or of two rings (*dicyclic*), which are distinguished as *infrabasals* (IBB), and *basals* (BB). The infrabasals, when present, form the proximal ring, and are radially disposed. The basals adjoin the radials and alternate with them, being interradial in position. By the law of Wachsmuth and Springer,[2] the elements of the crinoid skeleton from radials down to cirri successively alternate with each other in position; so that in descending order from the radially situated infrabasals in a dicyclic crinoid the pentameres of the stem when longitudinally divided are interradial, and the vertical sutures and cirri radial; the outer angles of the stem, when pentagonal, are usually interradial; the sides of the stem and the outer angles of the lumen for the axial canal radial—the last three cases being subject to exceptions due to secondary growth. In a monocyclic crinoid these positions are reversed. By attention to these relations it is possible from the position of the cirri, and frequently from that of the angles of the stem or axial canal, to determine whether a specimen is dicyclic or not, though the infrabasals cannot be seen. There are no angular stems among the Flexibilia; and all of them are dicyclic.

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[1] Clark, A. H., Bull. 82, U. S. National Museum, pp. 59-108.

[2] North American Crinoidea Camerata, 1897, p. 60; Bather in Lankester, Zoology, pt. 3, 1900, p. 106.

*Radials* (RR). The circlet formed by the first plate in each of the rays, or, the radially situated circlet of plates above the basals, and this ring only. In some of the earlier crinoids one or more of the radials appear as if transversely bisected, the lower segment of the compound plate being called the *inferradial,* and the upper segment the *superradial.* A *ray,* or *radius,* is the radial plus all the structures which it bears; an *interray,* or *interradius,* means all structures between the rays; these terms are usually employed for structures considered from the dorsal side, but properly speaking they include both dorsal and ventral structures.

*Brachials* (Br). All plates beyond the radials in radial succession to the ends of the arms. They are called *fixed brachials* in so far as they take part in the calyx; *free brachials,* or *arm-plates,* when they do not. The brachials forming the first circlet above the radials, whether fixed or free (formerly "costals"), are called *primibrachs* (IBr); those of the second order (formerly "distichals"), *secundibrachs* (IIBr); those of the third order (formerly "palmars"), *tertibrachs* (IIIBr): and so on for the succeeding orders of brachials to which formerly the name "post-palmars" was applied. A particular brachial in any series is denoted by placing a small Arabic numeral after the symbol—$IBr_2$, $IVBr_6$. The axillary brachials may be designated IAx, IIAx, etc.

*Ambulacrals* (Amb). The rows of small plates enclosing the food-groove in the tegmen and arms. They consist of *adambulacrals* or *side-pieces,* and *covering-plates;* the former when present constitute the outer, the latter the inner, rows of plates. The covering plates form a roof over the food grooves; they are generally represented by two alternating rows of small plates, more or less regular in their arrangement, which are movable upon the arms and pinnules, but upon the disk only in those crinoids in which the mouth is exposed.

*Interradials* (iR). All plates occupying the spaces between the rays proper, whether they belong to the dorsal cup or to the tegmen. *Interbrachials* (iBr). Interradials in the dorsal cup which are interposed between the brachials of the several orders. Plates between brachials of the second and higher orders are *intersecundibrachs,* etc. (iIIBr, etc.); those of the tegmen which lie between the ambulacra are *interambulacrals* (iAmb). The term "interradials" includes all interbrachials, but the term "interbrachials" does not include those interradials which lie within the radial circlet; the latter plates, however, are not normally represented in the Flexibilia, so that so far as this group is concerned the two terms are synonymous.

*Radianal* (RA). A plate disturbing the bilateral symmetry of the cup, located primitively directly below the right posterior radial (being an inferradial restricted to the right posterior ray), and in later genera obliquely to the left of it, either at the lower or the upper corner.

*Anals.* Interradials of the posterior side, forming the base of the anal structures. The *special* or *first anal* plate (now usually designated $x$) when present usually rests upon the truncated upper face of the posterior basal and between the radials. Higher anal plates may be present, even when the special anal plate is wanting; they are interposed between the interradials, following the median line of the posterior area, and may extend upward along the tegmen where they form the backing or support for a conical tube. The first plate of the tube may in some cases represent the radianal.

*Anus* (As). The excretory orifice of the rectum, intestine, or hind gut. It is interradial in position; its opening may be central, excentric, marginal, or lateral; placed at the distal end of a central or sub-central tube, directly through the disk, or through the dorsal cup at the angle between basal and radials; it is located at all intermediate positions between these extremes, according to growth of the gut. The *anal tube* is subject to singular modifications in size and shape, from a small conical protuberance to a large club- or balloon-shaped appendage, often far exceeding the calyx in size. The latter is a marked feature of certain Fistulate crinoids, in which the anal opening often appears at the anterior side, and may be located at the base of the tube, midway toward its summit, or at the end of a lateral spout.[1] These facts have given rise to the impression that the appendage in such forms may have had other than anal functions, and it has therefore been called the ventral sac, as distinguished from a mere tube. Later investigation shows that this supposition is unnecessary, as all forms of tube in which the anus is not at the distal end may be explained by the recurving of the gut toward the anterior side, redoubling upon itself more or less completely, so that the opening may emerge from the wall of the tube at any point between the distal end and the base.

*Orals* (O). The five large interradially situated plates which surround or cover the mouth. They are said to be *symmetrical* when of nearly the same size and form; *asymmetrical* when the posterior plate is pushed in between, or is larger than, the other four. In some forms permanently, and in some temporarily, they occupy the entire ventral surface of the calyx; in others only a comparatively small space in the middle of the tegmen; or they may be completely resorbed in the mature individual. Some or all of the orals may be perforated, serving the purpose of a madreporite.

*Perisome.* The pliant integument, whether naked skin or studded with undifferentiated plates or spicules, which covers the ventral side of the calyx in the Flexibilia and in the Mesozoic and Recent crinoids, surrounding the mouth, supporting the food-grooves, and extending for varying distances down between the rays and their divisions. Morphologically the perisomic plates include the interradials and interambulacral plates, and in its plated condition the perisome is regarded as the morphologic equivalent of the solid vault of the Camerata. In some forms of the Inadunata classed as the Fistulata, the perisome of the posterior interradius of the disk is extended upward into a large sac lodging the enlarged gut recurved and redoubled upon itself.

*The mouth* occupies the center of radiation, and is either *tegminal* or *subtegminal*. If tegminal, or exposed, as in the Flexibilia and Articulata, the opening is surrounded by the orals and ends of the ambulacra, or when orals are absent by interambulacral plates which form a lip around it. If subtegminal, it is completely closed, as in the Camerata and Inadunata, by orals, fixed ambulacrals, or interambulacral plates, which form a roof over it. The *ambulacra* radiate from the mouth or oral center to the ends of the rays, following the ventral furrows of arms and pinnules. When subtegminal, they enter the calyx through the arm openings at the upper edge of the dorsal cup; when tegminal, they follow the surface of the disk. They contain the food-grooves, ambulacral and ovarian vessels, and the axial canal. The *food-groove* forms the upper passage, and beneath it in order lie the subtentacular canal, the genital canal, and the axial canal. The *axial canal* contains the *axial nerve cords* which communicate with the *chambered organ* at the dorso-central basin of the calyx, from which they also pass downward into the stem. In most of the Paleozoic crinoids permanently, and in the *Antedon* larva temporarily, the axial canals of the calyx are mere grooves at the bottom of the ventral furrow; but in the adult Recent crinoids, and in a few Paleozoic forms, they are separated from the furrow by a limestone partition, producing what is called a *dorsal canal.*

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[1] See North American Crinoidea Camerata, various figures on Plate VII.

The mode of union between the plates of a crinoid is either by *suture,* or *articulation.* The first may be by close suture, loose suture, or anchylosis or fusion. A *close suture* is an immovable union in which the apposed surfaces are flat, and may be smooth or striated, and the plates are united by short fibres of amorphous tissue: *e. g.,* between the calyx plates of the Camerata. In a *loose suture* the faces are more or less concave or excavated, lodging bundles of ligament, with contact areas of smooth facets or of interlocking crenulations, thus allowing a certain amount of motion between the plates: *e. g.,* between the calyx plates of the Flexibilia, and to a lesser degree between the stem ossicles of most Paleozoic crinoids.

*Anchylosis* is a modified close suture in which the lines of union have been obliterated by subsequent deposit of stereom, or fused. *Syzygy* is a special kind of close union usually by flat striated faces, sometimes called a non-muscular articulation, found only in arms and stem interposed between two of the ordinary joints and by which two ossicles are rigidly united into one compound ossicle.

*Articulation* is a movable connection between plates of the radial series and between columnals of some crinoids. It may be: (1) Upon undifferentiated joint-faces, by concavo-convex surfaces, usually without transverse ridge: Cyathocrinidae, and senile condition in some Recent crinoids. (2) With fossae, paired muscles and ligaments, but mostly without transverse ridge: Flexibilia, with slight exceptions. (3) Complete muscular articulation, with highly developed facets, fossae, transverse ridge, and paired muscles and ligaments: Poteriocrinidae *sensu* Wachsmuth and Springer; Mesozoic and Recent crinoids with a few exceptions; and in the flexible free arms of the crinoids generally. For details of other articulations more especially applicable to the Recent crinoids, see Clark, Monograph of the Existing Crinoids, p. 66.

*The orientation* is based upon the natural position of the crinoid, with the arms uppermost, and viewing the specimen from the anal side. The anal interradius will then be posterior, the radius opposite to it anterior, while the right and left sides will correspond with the right and left of the observer. In illustrations the dorsal view is drawn with the anal interradius up, and the ventral view with the anal side down. Right and left remain the same in both cases. Next to the anterior ray are the right and left anterior or antero-lateral rays, or more conveniently called lateral rays; and adjoining the anal interradius the right and left posterior rays. Corresponding appellations are applied to the interradial spaces, which consist of the two anterior, the two postero-lateral, or simply lateral, and the posterior or anal interradius.

*Dorsal.* The surface opposite to that which includes the mouth and ambulacra: aboral. Under normal conditions it is the lower external surface of the crown, as opposed to the surface next to the viscera.

*Ventral.* The surface upon which is situated the mouth and ambulacra: adoral. Uppermost under normal conditions, and when speaking of plates the surface or direction toward the viscera.

*Proximal* and *distal* are reckoned from the plane separating stem from crown, so that the infrabasals and the top columnal are the proximal elements of crown and stem, respectively. In the crown, the outer surface of a plate is the dorsal side, the lower edge the proximal face, its upper edge the distal face, and the faces at the sides are the lateral faces. In the stem, the upper face is the proximal, and the lower the distal. *Proximale,* a term applied to the uppermost columnal.

## MORPHOLOGY

As already stated, knowledge of the crinoids included in the group Flexibilia is of much later date than that of the other major divisions. The first illustration in the literature of a specimen belonging to this group is a figure of *Ichthyocrinus pyriformis* published by Ellis [1] in 1762, without name, in connection with an account of a Recent stalked crinoid from Barbados; this was afterward refigured by Parkinson [2] in 1808 under the name of the "Fig Pentacrinite." The next was that of a specimen of *Amphicrinus scoticus* figured by David Ure [3] in 1793, under the name of *Encrinus.* The first species to be named was J. S. Miller's *Cyathocrinus tuberculatus* described in 1821. When in 1841 Johannes Müller wrote upon the structure of the Crinoidea, not a single genus belonging to this group had been proposed, and not until 1877 was the type upon which it was founded recognized as of more than family importance. This slow progress of investigation in a group which is now represented by 31 genera was primarily due to the rarity of their occurrence. Of the first genus, *Taxocrinus,* founded by Phillips in 1843, probably not half a dozen specimens were known in England. De Koninck and Le Hon's type and only European species of *Forbesiocrinus,* from the Belgian Carboniferous, was only known by their two original specimens from 1854 until I obtained the new material figured in this work. Three species belonging to this group were quite abundant at the celebrated locality of Crawfordsville, Indiana, and have been distributed among the museums of the world in later years; but aside from these the Flexibilia have been, and are to this day, among the rarest fossils in the rocks. Some localities with an abundant crinoidal fauna have not produced a single specimen belonging to this group.

This paucity of remains is not due to any special fragility of construction; on the contrary these fossils are for the most part well adapted to preservation. As the name indicates, the group is characterized by a certain flexibility of the calyx due to the presence of loose sutures with elastic ligament between the plates, admitting of considerable mobility. At the same time the plates are usually very thick, their depth frequently exceeding their length or width, so that the apposed faces are relatively large, and the plates are fitted together like bricks in a pavement. Consequently in the process of fossilization the calyx was not easily broken by pressure, but tended to remain intact when enveloped by the mud of the sea bottom, although yielding to some extent, and therefore in many cases found flattened in the rocks. In some genera, however, such as *Ichthyocrinus, Forbesiocrinus,* and *Parichthyocrinus,* the walls are so thick that the fossils are often perfectly rotund. This feature of extreme thickness of the plates may be seen in various figures on Plates XXI, XXIII, XXIV, XXXI, XXXIX, LVII, LXI. I know of no instance of a Flexible crinoid with thin calyx walls, except rarely at the very lowest part in some forms of *Ichthyocrinus* (Pl. XXXVI, fig. 6*c*).

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[1] Philosophical Transactions, Roy. Soc. London, vol. 52, Pt. I, p. 357, pl. 13, Fig. B.

[2] Organic Remains of a Former World, vol. 2, pp. 258, 270, 274, pl. 19, fig. 2.

[3] The History of Rutherglen and East-Kilbride, pl. 18, figs. 13, 16.

Another fact conducing to preservation was the tendency in the species of many genera to close infolding of the arms at death, so that the entire crown was rounded like a ball. This was aided by a peculiarity in structure which extends throughout the entire group, and forms one of its most distinctive characters, viz., that the arms, instead of being free and completely differentiated from the calyx, as in the Inadunata and most of the Camerata, either lie in close contact, or for a part of their length are connected by plates or perisome, or form a direct continuation of the radial series of the calyx, so that there is no distinct line of demarkation between them. This mode of construction gives to these forms a peculiar habitus which is in marked contrast with those of the other two orders, and by which the specimens can as a rule be readily recognized from small fragments; and from the strong predominance of this character it also results that distinctions between the subordinate divisions of the group are not so sharply marked as are most of them in those orders.

Neither is the rarity of these fossils due to restricted distribution. They occur in most of the crinoid-producing regions of America, Britain, and continental Europe, from Spain to Sweden and Russia. And they range from the Lower Ordovician to the Lower Coal Measures (Pennsylvanian); though what became of them in certain horizons and localities otherwise prolific in crinoids is a mystery. In the Upper Ordovician of the Cincinnati area, and in the Onondaga and Hamilton of the Louisville area, both of which have yielded great numbers of other crinoids, not a vestige of any species of the Flexibilia has ever been seen, although in the Hamilton of other localities they are not unknown.

Withal, the Flexibilia form a good zoological group, well balanced and differentiated from others, containing within itself subordinate modifications due to morphological changes of fully as great importance as those found in other orders, and in some respects parallel to them.

In the Monograph of the North American Crinoidea Camerata by Wachsmuth and Springer, 1897, pp. 38 *et seq.,* it was shown that the elements of the crinoid skeleton fall into two groups, viz., *primary* plates, and secondary or *supplementary* plates—the former being those first developed in the larva, represented in every group of the class, and undergoing few modifications in geological time, the latter being interposed between the primary plates and helping to increase the capacity of the visceral cavity; that the latter appear in the growing crinoid, but are unrepresented in some of the groups; that they are subject to great modification, and therefore have a high taxonomic value. The primary plates were subdivided into two classes; plates of the *abactinal,* and of the *actinal* systems; the former including all plates connected with the chambered organ and axial cords, the latter those connected with the mouth and food canals; the former being represented by the columnals, infrabasals, basals, radials, and plates forming the dorsal parts of arms and pinnules, the latter by the orals and ambulacral plates of tegmen and arms. All the others were shown to be supplementary pieces, being the interradial or interbrachial, and the interambulacral systems. A general morphological discussion of these elements followed, applicable to the crinoids of all groups, which has since been supplemented by the great work of Bather in the Lankester Zoology; and by these the whole subject has been thoroughly covered, so that there is no need for me to enter upon it here. But I shall follow substantially the same order as in the Camerata in describing the skeleton of the Flexibilia.

The dominant general character of the group Flexibilia is the distinctive facies due to its strong, well-united, and flexible calyx passing almost insensibly into the arms. As Bather has well expressed it,[1] " it is the combination of massiveness with flexibility that characterizes the Grade." These features are produced, the first by the thickness of the plates, and the second by their mode of union with each other. This union is by muscular articulation between plates of the radial series, while between these and the supplementary plates, and the latter among themselves, it is of the type of loose suture; both are characterized by fossae for the lodgment of ligament bundles, and contact areas of crenulated surfaces. Upon the relative predominance of these elements depends the greater or less looseness of the union and consequent flexibility of the calyx. In this there is much variation, from that of forms like *Forbesiocrinus nobilis* with extremely large and deep ligament fossae and narrow bands of contact surface (Pl. XXIV), to that of *F. saffordi* with shallow and restricted ligament fossae and numerous small contact areas (Pl. XXXI). In some forms with globose calyx and strongly differentiated arms, like *Nipterocrinus* (Pl. XV), it is probable that the union among the calyx plates was nearly that of close suture; these are in some respects transition forms toward the Inadunata. Added to the foregoing general characters is that of the arcuate or wavy sutures between plates of the brachial series, to be described presently, which imparts a highly characteristic appearance to the specimens.

In size of the specimens there is considerable diversity, the genera of the globose type such as *Lecanocrinus* being in general rather small, some not exceeding 5 mm. in diameter of the calyx, while others with a more elongate habitus like *Forbesiocrinus* attain a width of 8 cm.

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[1] Lankester's Zoology, pt. 3, 1900, p. 187.

As to surface characters, there is but little variety within the group. With the exception of low radiating ridges on the calyx plates of *Pycnosaccus* and one species of *Lecanocrinus,* or following the median line of the ray in some *Ichthyocrinus,* and of some ornamentation on the arms of a few species, the surface is everywhere either (1) finely pustulose, composed of distinct pustules or small nodes formed by actual elevations, sometimes coalescing into more or less distinct lines or wrinkles; or (2) smooth or finely granular, in the latter case consisting of granulations formed by the network of stereom, which should be called smooth.

## A. THE PRIMARY PLATES

### I. Abactinal System

### *a. The Column*

The column of the Flexibilia is always circular. Pentagonal, elliptic, or square stems, such as occur in the other orders, are unknown in this. The most marked characteristic is a series of very short and broad columnals, occurring at the proximal end, and diminishing in diameter while slightly increasing in length for a short distance, until the stem becomes cylindrical. There is thus produced a conical enlargement of the stem next to the calyx which is a conspicuous feature in many of the genera; it usually changes over gradually into the cylindrical portion, but in one case the enlargement contracts abruptly. This series of almost uniformly short discoid plates represents a diminishing series of successive proximales, without any intercalation of other ossicles. Rarely this process continues throughout the entire column (Pl. XIII, fig. 11*a*); sometimes without any taper (Pl. XV, fig. 5). Frequently the columnals increase in length distally until there is a complete reversal in proportions; in other cases the stem maintains an almost uniform diameter and length of columnals until it ends in branching roots formed by radicular cirri (Pl. LXXI), with nodal ossicles irregularly distributed. The proximal enlargement is most prevalent in the Carboniferous genera, although found in the Silurian, and in the very earliest species of the group in the Lower Ordovician. In the majority of Silurian genera it is wanting, the stem being cylindrical throughout and largely composed of alternating long and short ossicles, which often alternate in diameter also; the contrast in relative length in some cases is very great (Pl. XI, fig. 15*a*), extending to practical elimination of the short ossicles (Pl. VIII, fig. 5*a*); in some there is no alternation (Pl. XV, fig. 5); and in one species of *Mespilocrinus* the columnals become greatly elongated and barrel- or spindle-shaped (Pl. V, fig. 5).

There is much diversity in length; in some genera, such as *Calpiocrinus,* the stem is very short and thick, being with its expanded root not longer than the crown (Pl. VII, fig. 1*b*); these were probably littoral or circumlittoral species living in shallow water where they were exposed to currents. The longest stem occurs in *Onychocrinus,* attaining in *O. ramulosus* a length of 36 inches, ending in a point with lateral root branches. This was probably the prevailing mode of attachment to the sea bottom; but there are a few cases in which the stem ends in a flat or encrusting plate for attachment to other objects, as in *Calpiocrinus* above cited, and in at least one species of *Taxocrinus* (Pl. L, fig. 1); these are sporadic appearances of a character which becomes general in the Mesozoic Apiocrinidae.

Cirri are rarely observed, and were probably absent in most of the genera, as in the Apiocrinidae; when present, they are usually in the form of radicular branches toward the distal end (Pl. LXXI). Regular lateral cirri, extending for the full length of the stem, as in some Camerata and Inadunata and in many Recent stalked crinoids, are unknown, and probably did not exist in this group. In the few instances where cirri have been observed along the stem for some distance from the bottom, they are rather far apart, and their distribution irregular; they usually occur in broken whorls, one or more of the potential five being missing. Those which are present maintain their proper relation to the primary nerve cords, thus falling into five interrupted longitudinal rows. They are given off horizontally, and the sockets are confined to the nodal columnals as in *Isocrinus asteria* and *I. wyville-thomsoni.* The radicular cirri, which are usually much larger, are also given off from single ossicles, but stand at an oblique angle with the stem, resting in deep, funnel-shaped sockets, which involve three or four other ossicles (Pl. LXXV, figs. 15*a, b*).

The axial canal and lumen of the stem will be considered under the next head.

Distalwards the columnals undergo a variety of modifications in different genera. In some they remain smooth and even, without alternation (*Nipterocrinus*); in some they alternate irregularly between long and short (*Lecanocrinus*), and in others rather regularly (*Calpiocrinus*); in some they change from alternating to uniform (*Pycnosaccus*); and in some they are strongly convex like a string of beads (*Hormocrinus*); in one rare species there is an almost uniform taper from the calyx to the distal end, with very short and decreasingly wide ossicles in the upper half and changing in proportion from six times wider than long proximally to four times longer than wide distally (Pl. XIII, fig. 11*a*); again the stem may enlarge in the median part and then taper off toward the distal end (Pl. LII, fig. 4). As in the Recent crinoids, the stem ossicles are proportionally much the longest in young specimens (Pl. LVI, fig. 10).

The differences noted are not always constant for the genus. Complete stems are rather rarely found, so we do not know as much about them as is desirable; the characters are not, in practice, of much service in the differentiation of groups, the stem in this order, as in the Paleozoic crinoids generally, not having attained that fixity of structure which renders it an element of such great importance in the Recent crinoids. Occasionally, however, a stem character is remarkably constant for a species; for example in *Taxocrinus colletti* from Crawfordsville, Indiana, the most abundant species of a Flexible crinoid known, where the enlargement next to the calyx, instead of tapering gradually downward until it merges into the cylindrical stem, is invariably short and thick, ending abruptly with a rounded offset (Pls. LVI and LVII).

There is no reason for thinking that the mode of growth of the stem in the Flexibilia is essentially different from that in the other permanently stalked crinoids, viz., by means of new ossicles introduced next to the calyx, or interpolated between older ossicles within a short distance down. Upon this point the view of Wachsmuth and Springer expressed in the North American Crinoidea Camerata, pp. 39, 40, viz., that in this group the topmost columnal was persistently fused with the infrabasals so that the column increased by the interpolation of new ossicles below it, is in my opinion more theoretical than practical. That such a fusion often occurred in adult specimens in which stem growth was completed is doubtless true, as is indicated by specimens like those of figure *2a*, Plate XXVI, and figure 9, Plate LXXIV. But those occurrences, where the infrabasals became detached from the rest of the calyx and adhered to the stem, are rather to be explained by the nature of the union between the plates: (1) that between infrabasals and the succeeding basals being by loose suture, with large and deep ligament fossae and small contact areas (Pl. XXIV, figs. *1a, b*); while (2) that between infrabasals and stem was by plane surfaces with very fine radiating striae, *i. e.*, syzygy—a closer union than that of the stem ossicles with one another. The second connection was therefore stronger than the first, and with decomposition the infrabasals would separate from the basals rather than from the stem. The proximal ossicles in most of the Flexibilia were exceedingly thin, sometimes translucent in the fossil (Pl. XXX, fig. 5*a*), and their often persistent attachment to the infrabasals can readily be accounted for by a close suture without need of invoking an actual fusion, although this also may have occurred in mature individuals.

Such attachments are frequently found in *Forbesiocrinus* and *Onychocrinus;* but in many other genera nothing of the kind occurred, the stem separating from the calyx by a perfectly smooth surface (not of fracture). This was probably the case in most of the Silurian genera, in which the stem increased by alternating long and short columnals without proximal enlargement; and it is notably so in the Carboniferous genus *Amphicrinus,* in which every one of over 20 specimens has the topmost stem ossicle clearly separated from the calyx. It was probably the case also in the entire family Ichthyocrinidae, where the infrabasal circlet is much smaller in area than the proximal columnal, and takes the form of a plug at the center of the basals, in which the plates stand at a different angle from the stem ossicles (text-fig. 11).

It now seems clear that the idea of fusion between infrabasals and top columnal so as to prevent the interpolation of new segments must be limited to those crinoids in which the stem is only a temporary structure, and the infrabasals disappear at an early stage by absorption into the proximale which takes the place of a stem, or in which the infrabasals are so enveloped by the proximale as to lose their identity completely. Therefore it only applies to the comatulids and some Mesozoic crinoids, and not to the Flexibilia as now restricted. W. B. Carpenter's luminous description [1] of the development of the stem in the larval *Antedon rosaceus,* in which he shows that while the original segments are advancing toward completion "new segments are being developed . . . . between the highest of these and the base of the calyx," took no account of the infrabasals, whose existence in the comatulids was at that time unknown. In the closely related species in which these plates were first discovered they are fused with the top columnal at a very early period in stem growth; while in *Promachocrinus,* in which they are better developed than in any other known comatulid, they are fused with the upper ossicle in the prebrachial stage, and disappear from view externally long before the stem is completed and cast off.

Mr. Austin H. Clark has given much attention to the study of the column, which he finds in the Mesozoic and later crinoids to present the most reliable characters for broad systematic differentiation, in contrast to the Paleozoic forms in which the variations in calyx structure far outweigh the characters offered by the column. In his Monograph of the Existing Crinoids,[2] referring to the proximale in Recent and Mesozoic crinoids, and having explained that proximales, or columnals homologous to proximales, are always attached to the columnals just below them by a close suture called the stem-syzygy, and that the nodals throughout the stems in which they occur, with their syzygially united infranodals, are reduplications of the proximale, he states on p. 213:

> The formation of the proximale, closely attached to the dorsal surface of the calyx and fused with the infrabasals, prevents the formation of new columnals above it, and marks the maturity or end of growth of the stem. But the columnal formation may continue by intercalation between the columnals immediately below the stem syzygy, or excessive vegetative power may shove the proximale outward before it fuses with the calyx. In the adult pentacrinites new proximales are continually forming beneath the calyx, where every new columnal formed is a proximale, only to be pushed outward by younger ones. Later these become separated by intercalated segments, each of them becoming united by syzygy to the intercalated segment immediately below it.

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[1] Philosophical Transactions, Roy. Soc., London, 1866, sec. 63, p. 730.

[2] Bull. 82, U. S. National Museum, 1915, p. 212 *et seq.*

As to the occurrence of the proximale generally he says on p. 212:

> All Recent and Mesozoic crinoids possess a proximale or strictly homologous structure, typically single and attached permanently to the calyx, as in *Millericrinus, Bourgueticrinus, Phrynocrinus, Thiolliericrinus,* and the comatulids; but sometimes multiple, occurring all together just under the calyx, as in *Apiocrinus;* or at regular intervals throughout the column, as in the pentacrinites; or at frequent intervals in the proximal portion of the column and becoming less common distally, as in *Proisocrinus, Rhizocrinus, Bathycrinus, Monachocrinus,* and *Democrinus.*

The second of these types of column, viz., with multiple proximales just under the calyx, is comparable to that of those Flexibilia having a proximal enlargement; while the stems of the remainder might fall substantially under the fourth type—the nodal columnals being for the most part irregularly distributed. Every modern type of stem may be found in some Paleozoic crinoid, but in none of the ancient groups had the stem characters become fixed and correlated with other characters as in the later crinoids.

Absence of a stem, and substitution therefor of a direct attachment by the base as in some species of *Edriocrinus* or the remarkably similar Recent *Holopus,* or of a free floating existence as in the Inadunate genus *Agassizocrinus* or the adult comatulids, is not known among the Flexibilia.

### *b. Infrabasals and Basals*

All Flexibilia have a dicyclic base, with three unequal infrabasals, which exceptionally disappear by atrophy, are fused into a solid plate in *Nipterocrinus,* or appear as the primitive five in one species of *Mespilocrinus.* In this character they are in contrast to the dicyclic Camerata and Inadunata, which have five equal infrabasals, with exceptions in the latter. The small infrabasal is radially situated, as the primitive segments of the other two would be if they were bisected; but it would seem that the coalescence (if that is what happened) of the two pairs, or the non-division of the two larger plates (if that was the primitive condition as in some comatulids) was attended by consequences which mark a rather wide difference between dicyclic crinoids with five equal infrabasals and those with three unequal ones. Normally, as pointed out by Wachsmuth and Springer (N. A. Crinoidea Camerata, pp. 58, 153), the small infrabasal is in the right posterior position; but to this exceptions are found in some species of *Forbesiocrinus* where this plate lies at the anterior (Pl. XXX, figs. 5*b,* 7*a*), or the left posterior (*ibid.,* fig. 10), and rarely in one or two other genera.

In the Lecanocrinidae the infrabasals are usually prominent and erect, forming a part of the calyx wall at the exterior. In the Ichthyocrinidae, however, they are buried under the column, lie almost flat, and take no part in the formation of the exterior wall. Being thus without the function of calyx plates, they exhibit in this family a marked tendency to atrophy. In two species of *Ichthyocrinus* they are found completely resorbed (Pls. XXXV, figs. 4*b*, 5; XXXVI, figs. 3*a*, *b*). In Plate XXXV, figure 5, it will be observed that the lumen of the axial canal, instead of being radial as usual in the genus, has with the disappearance of the infrabasals become interradial in position. The same thing occurs in *Cleistocrinus*, where in one specimen the resorption involves part of the basals also (Pl. XXXVIII, fig. 2*b*). In the two Carboniferous species of *Euryocrinus* the infrabasals are partly or wholly resorbed (Pl. XL, figs. 4*a*, 7*b*), while in the Devonian representative of the genus they are intact (Pl. XL, fig. 1*d*). In *Amphicrinus*, the latest survivor of the Flexibilia, the infrabasals are often partly, and in some cases entirely, resorbed; and here we have the converse of the occurrence in *Ichthyocrinus*, for while the axial canal in the genus normally has its angles interradial, in three specimens where the infrabasals have completely disappeared the lumen has become radial (Pl. XL, fig. 9*b*). Thus in these cases there seems to be a change from a dicyclic to monocyclic base within the same species, accompanied by a corresponding change in the orientation of the axial canal. It is noticeable that in these cases of resorbed infrabasals there is usually an open space in the position they would have occupied larger than is required for the stem lumen. A similar fact is seen in the Recent *Endoxocrinus parrae*, which in contrast to other closely related forms of the Pentacrinidae has no infrabasals.

An extraordinary modification of infrabasals in the opposite direction from that of the Ichthyocrinidae is found in the Silurian genera *Homalocrinus* and *Calpiocrinus*, in which these plates are enormously enlarged, so that they envelop, and in some cases completely conceal, the basals and even the radials (Pls. VI, figs. 1*c*, 2*b*; VIII, figs. 3, 7*b*, *c*). This is a condition which does not exist in any other crinoid. I first called attention to it in 1906,[1] before which date the structure of these two genera had been wholly misunderstood; and the full details will be found later on in the appropriate generic discussion.

The nervous system of the crinoids is centered in the chambered organ, which in some of the Flexibilia was lodged in a peculiar funnel-shaped cup on the inner floor of the infrabasals, presently to be described. That the seat of vitality was located at this place is proved by a case of recuperation in a specimen of *Taxocrinus*, where the calyx had been broken away in life leaving only the infrabasals and one basal, from which a new crown was produced with six rays (Pl. LVI, figs. 11*a*, *b*, *c*). In genera like *Ichthyocrinus* of which the infrabasals, having lost their original function, were too small to accommodate such a funnel, it moved up to the basals (text-fig. 1*a*). A similar structure is found, variously modified, in specimens belonging to the orders Camerata and Inadunata, both monocyclic and dicyclic.

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[1] Journal of Geology, vol. 14, p. 480.

Although the stem in the Flexibilia is always circular exteriorly, the lumen of the axial canal is pentagonal, or quinquelobate, so far as observed; in some genera it is very small and possibly round, but in many of the most prominent forms it is of good size. The base being dicyclic, the angles of the lumen, if they represent the orientation of the axial organ and its downward extensions, should in accordance with the law of Wachsmuth and Springer[1] be radial in position; and in some genera, such as *Ichthyocrinus, Lecanocrinus, Homalocrinus, Calpiocrinus,* and *Pycnosaccus,* they seem to be so. But in other genera they are either distinctly interradial, or while not quite regular are more interradial than radial. Observations on this point, however, are usually limited to the aspect of the canal where it enters the base, being exposed by the detachment of the stem at that level. Here the orientation is complicated by the fact that there are only three infrabasals, which are unequal. The canal in the stem of crinoids lodges the five axial nerve cords, which are downward prolongations of the lobes of the chambered organ, with their nerve-fibrillar investment; if the base be monocyclic, they pass directly from the basals into the stem, and are therefore interradial in position; if dicyclic, they enter the stem from the infrabasals, and are radial (see Bather in Lankester's Zoology, pt. 3, pp. 103-104).

This would be simple enough in crinoids with five infrabasals; and it might be supposed that the cords would branch from the basals to the infrabasals symmetrically even when there are only three, treating the two larger ones as representing primitive pairs. But in many of the Flexibilia, perhaps all, the lumen for the passage of these cords into the stem is connected with a very peculiar structure at the inner floor of the calyx where the lumen begins. Here the opening is surrounded by a thin raised rim which spreads into a lobate, funnel-shaped vessel, having broad, shallow channels leading down toward the stem; the channels, or chambers, are separated by septa, and the funnel as thus divided undoubtedly lodged the chambered organ with its nerve-fibrillar envelope. In *Ichthyocrinus,* where the infrabasals are generally reduced in size and sometimes entirely resorbed, they are too minute to lodge such a structure; it is therefore formed at the edges of the five basals, and is five-lobed and subpentagonal in outline (Pl. XXXIII, fig. 9*c,* and text-fig. 1*a*). The very thin internal septa which bound the chambers of the funnel curve in their downward course sufficiently to cause a partial revolution in position of the channels from interradial in the upper part to radial where they enter the stem. A more detailed account of this structure is given in the generic discussion under *Ichthyocrinus.*

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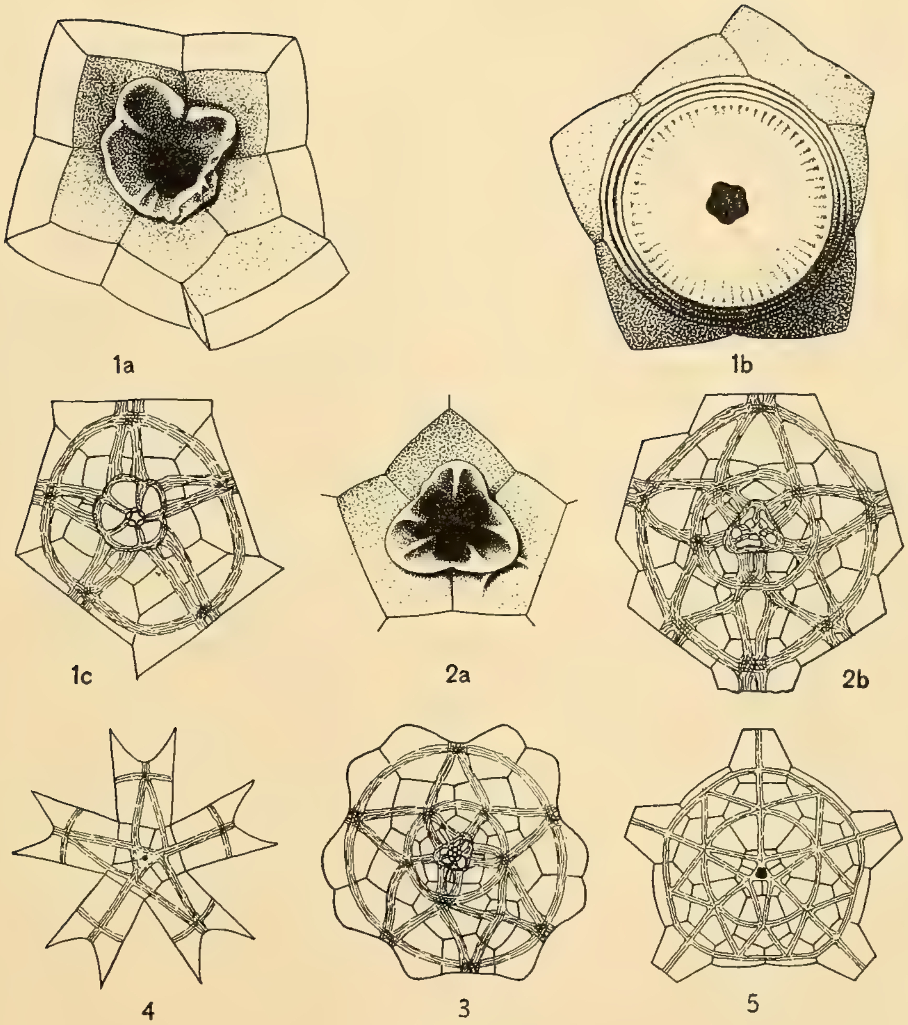
[1] Revision of the Palaeocrinoidea, pt. 3, sec. 1, 1885, p. 7; N. A. Crinoidea Camerata, 1897, p. 59. At the time of these discussions neither Wachsmuth nor I were aware of the important paper by Beyrich "Ueber die Basis der Crinoidea brachiata," Monatsber. Akad. Wiss. Berlin, Feb. 1871, p. 33, in which some of the facts upon which the law was based were lucidly stated. For that reason the proper credit was not given.

In *Forbesiocrinus,* with large infrabasals, the rim rises from their inner edges, and is triangular or trilobate in general outline, the apices resting medially upon the plates and coinciding with them in relative position (Pl. XXX, figs. 5*c*, 6*c*, etc.). The internal cavity of the funnel is divided into five unequal channels continuous with those of the stem lumen; three large channels are opposite the infrabasal sutures; while the two small ones are median upon the large compound plates. With the three lobes of the funnel thus coinciding exteriorly with the three unequal infrabasals, we would naturally expect the same result as in *Ichthyocrinus* to be attained by division of the channels upon the two larger lobes; but instead of that, by a most singular arrangement of the septa (further described in the generic discussion under *Forbesiocrinus*), five unequal interradial channels are produced which pass with that orientation down into the stem (text-fig. 2*a*). The same three-lobed funnel accompanied by interradial orientation of the stem lumen occurs in *Taxocrinus* and *Onychocrinus.*

In *Lecanocrinus* and *Pycnosaccus,* where the infrabasals take a distinct part in the formation of the calyx wall, the tri-lobate funnel is also formed on their inner floor, divided by the septa into five unequal channels; but here, instead of the chambers as in *Forbesiocrinus,* it is the septa between the chambers which coincide with the infrabasal sutures (text-fig. 3); therefore the channels are radial in position, and pass into the stem with the same orientation as in *Ichthyocrinus,* but this orientation is attained by a different process.

Thus there is an absence of uniformity in the orientation of the axial canal, partly due to the presence of unequal infrabasals. In some cases of the *Forbesiocrinus* type the lobes of the lumen appear doubtful in position, partly radial and partly interradial, owing to the great excess in size of the three larger ones. This irregularity is mostly corrected within a short distance down the stem, where the lobes of the lumen are usually decidedly interradial, as shown by figure 14 on Plate XXX. A somewhat similar variation in the position of the stem lumen is seen in monocyclic Camerata with three basals. In those it should be strictly interradial, but examination of a large number of specimens shows that the orientation departs rather frequently from a perfectly regular position. It does not follow that the actual orientation of the nerve cords in the stem was subject to these irregularities.

The primary axial nerve cords proceed from the cavities or lobes of the chambered organ which is lodged within the ring of basals in monocyclic, or of infrabasals in dicyclic, forms. These cavities are prolonged downward into the stem in five peripheral vessels which surround the central vascular axis. These enlarge at the nodal ossicles, and from the nodal enlargements the cirrus vessels pass out, following the line of junction of the pentameres of the stem. Thus the orientation of the cirri, and of the peripheral canals with which they



Figs. 1-5

FUNNEL LODGING THE CHAMBERED ORGAN; STEM-LUMEN; AND COURSE OF DORSAL NERVE CORDS.

1a. *Ichthyocrinus;* IBB too minute to support funnel, which here rests upon basal ring; chambers coincide with IBB sutures and are therefore interradial in position; but in their downward passage the cords are revolved until they become radial in the stem. × 10. *1b,* dorsal view of same, showing radial orientation of stem-lumen. × 10. *1c,* diagram showing course of nerve cords.

2a. *Forbesiocrinus saffordi;* chambers coincide with IBB sutures, are interradial and pass into the stem in that position; small IB exceptionally at anterior. × 5. *2b,* diagram showing probable course of paired nerve cords—those of large IBB compressed into about the space of a single cord.

3. Course of nerve cords in dicyclic calyx, drawn from *Pycnosaccus.*

4. Course of nerve cords in monocyclic calyx with unequal basals as shown by external ridges, drawn from *Stephanocrinus angulatus.*

5. The same in monocyclic calyx with equal basals, drawn from *Steganocrinus pentagonus.*

connect, must necessarily be the same as that of the lobes of the chambered organ, the primary axial cords, and the proximal plates of the base, namely, interradial in monocyclic and radial in dicyclic crinoids; and the orientation of the original pentameres of the stem must alternate with them. It would be expected that these peripheral vessels, whose branches follow the suture lines of the original pentameres, would lie at the corners of the central opening formed by the junction of the pentameres, and that this central canal when angular or petalous would have the same definite orientation as the cirri, and be uniformly radial in dicyclic forms. But in fact we find that this is not always the case with the central canal formed by the hard parts of the stem as we find it in Recent crinoids treated with potash, and in fossil forms. In most species of *Isocrinus* and *Metacrinus* the canal, angular in the newer parts of the stem, is distinctly interradial, while the peripheral vessels are radial; and in the majority of the Flexibilia, so far as observed, the stem lumen as we see it is interradial.

In studying the question in the Recent crinoids, it is found that while the peripheral vessels in the stem form a pentagon whose outer angles coincide with the cirri and the vertical sutures, they do not fill the space within the stem lumen or central opening within the calcareous walls of the stem, but are surrounded by a fibrillar envelope of perishable substance which is destroyed by potash dissection; the same thing would happen during fossilization. These peripheral canals are relatively minute, and do not occupy more than half of the central opening surrounded by the calcareous substance of the stem (see P. H. Carpenter, Stalked Crinoids, pl. 24, figs. 1-4). Hence they can have nothing to do with determining the shape or orientation of that opening. Therefore it must be said that owing to secondary growth, or for some unknown reason, the form and orientation of the stem lumen are independent of the peripheral canals, and may or may not coincide with them. And the lumen may also have a shape totally inconsistent with the existence of any definite connection between them, as for instance in *Cupressocrinus, Schultzicrinus, Myrtillocrinus, Arachnocrinus,* etc., in which the stem canal may be three or four sided.

The foregoing facts confirm the view expressed by Bather in the Lankester Zoology, pt. 3, p. 106, that with regard to the orientation of the stem canal the law of Wachsmuth and Springer is empyrical and subject to exceptions. With the facts now known it would seem to apply chiefly to those forms, whether monocyclic or dicyclic, in which the plates of the lowest ring are equal, and even in those there are some exceptions. In view of the exceptions and irregularities thus observed, and of the variable shape of the stem canal in different genera and sometimes even within the same genus, as in *Cupressocrinus,* the orientation of the stem lumen may be regarded as a matter of minor importance in the morphology of the crinoids.

Perforation of the radials or brachials for the passage of the axial nerve cords, such as is common in the Recent and many Mesozoic crinoids, and is found in some Inadunata, has not been observed in this group, except in some of the brachials of *Forbesiocrinus* and perhaps in *Synerocrinus.* Indication of such perforation in the former is well shown on Plate XXIV, figures 8-15, which seem to represent stages of its development from a ventral furrow. In those parts of the calyx below the brachials the course of the nerve cords can in many cases be distinctly traced externally by ridges representing folds in the plates which pass from one to another. Such folds are very plain in *Pycnosaccus, Hormocrinus, Lecanocrinus waukoma, Steganocrinus pentagonus,* and in *Stephanocrinus angulatus,* but they have usually been considered as mere surface ornament. Bather[1] and Wilson[2] have noted the occurrence of a ridge upon the anal series in certain Camerata as showing the presence of a nerve cord passing beneath it to control the tube. There seems no reason to doubt that the position of the principal nerve branches supplying other parts of the crown is in some cases indicated by similar ridges upon the exterior of other plates. Such ridges occur in only a few genera of the Flexibilia, but their office as indices of the course of the nerve cords is very clear. That external evidence of the course of the nerve branches is not more generally afforded might be expected from the more diversified character of the nervous system in the ancient crinoids, whose highly specialized calyx is in marked contrast to the very simple and greatly reduced calyx of the modern forms. In some genera and species the ridges are broken up into bars, become spinose or nodose, or are reduplicated by systems of parallel ridges which obscure the primary ones. In many species the primary ridges are entirely absent, while in others they may be easily determined.

In normal radial innervation in dicyclic crinoids the central nervous organ rests within the infrabasals and its lobes are radial in position. From each lobe two obliquely diverging nerve cords pass to the centers of the basals, where they unite and are connected by the horizontal cord known as the basal commissure. From the center of the basals the nerves again diverge and pass to the radials, where after uniting in the radial commissure they continue on into the arms (text-fig. 3). In monocyclic crinoids radial innervation is even simpler; the nervous organ lies within the basal ring and its lobes are interradial in position. The two nerve cords from each lobe pass up into the radials, where they unite in the radial commissure and then go into the arms (text-fig. 5). Innervation of interradial structures in either form is probably effected by secondary branches from the radial trunks or from those arising on the basals.

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[1] In Lankester's Zoology, pt. 3, 1900, p. 119.

[2] Journal of Geology, vol. 24, 1916, p. 550.

The distribution of the primary nerve cords in the Flexibilia undergoes a significant modification in connection with the inequality of infrabasals, resulting from the reduction of the primitive five plates to three. The primitive five being equal plates, it would be expected that the two fused pairs would each have an area of two-fifths of the pentagon. But instead of that, measurements of all the detached bases of *Forbesiocrinus* like those figured on Plate XXX disclose the fact that the two undivided sides of the pentagon formed by the larger (fused) plates are shorter than the other three sides which each include parts of two primitive plates. Fusion of the two pairs has therefore been accompanied by retardation of their growth, or a relative compression. This is found to be the rule not only in the infrabasal pentagons of the other Flexibilia, but also in most unequally tripartite bases of monocyclic forms. It is true of the blastoids, of *Stephanocrinus,* and of the Platycrinidae, as has been proved by actual measurement of over 200 specimens of *Pentremites,* 50 of *Stephanocrinus,* and many bases of *Platycrinus.* Thus while the area of the combined pairs is relatively reduced, that of the single original plate is increased, so that this plate is usually found to be considerably more than one-fifth the area of the pentagon; in some cases the increase has been so great that the three infrabasals are not far from equal (Pls. LIII, fig. 2*c*; LXIII, fig. 4).

Such a reduction in size of the fused plates would seem to be the direct consequence of anchylosis.[1] Upon lateral fusion of pairs of the original five infrabasals (or basals in a monocyclic crinoid) marginal growth of the compound plate ceases along the lost sutures; and as plate growth and growth of the body wall take place only along sutural areas, such growth in the middle of the compound plate is inhibited. Growth in the nerve chambers corresponding to the fused pairs is also partially restricted, so that the funnel enclosing the chambered organ assumes a triangular outline. At the same time the two nerve branches which pass on either side of the lost sutures must be similarly retarded in their growth, and cannot always separate as they do in freely growing areas. Therefore, while the nerves proceeding upward from the chambered organ at those sides of the infrabasal pentagon which are composed of parts of two original plates are in pairs, those from the sides consisting of the fused plates are often apparently single as far as the basal commissure. The single nerve in the compound infrabasals, however, is really a double nerve with the halves closely apposed by means of the resulting compression, and is covered externally by a single ridge; this apposition of the two original nerve cords is subject to variation according to the greater or less degree of the compression, and, therefore, it may be found complete or incomplete in forms otherwise closely similar.

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[1] Wilson, H. E., Evolution of Basal Plates, Jour. of Geology, vol. 24, 1916, p. 541.

The coalescence of the two primary nerve cords on emerging from the proximal ring seems to be a frequent occurrence wherever pairs of the primitive five plates have been reduced to single plates by fusion. A good example among monocyclic forms is found in *Stephanocrinus angulatus* (text-fig. 4, p. 35) in which the external ridges are extremely well defined; here the ridges pass to the radials singly from the undivided faces of the two fused plates, while upon each of the other three radials a pair of ridges enter, one from each side of the interbasal sutures. Among the entire set of ridges two are always narrower than the rest, and it will be seen from the figures that owing to the increased size of the odd basal one sutural face of the fused pairs is shorter than the others; it is invariably those shorter faces that are traversed by the two smaller ridges. In this species the shape of the nerve-center is indicated externally by the sharply triangular cross-section of the basal cup. A similar relation of the external ridges appears in the Camerate species *Steganocrinus pentagonus* (text-fig. 5), where owing to the interposition of an anal plate the base consists of three equal plates forming a hexagon; the ridges passing to the three undivided sides of the hexagon are single, while those entering the other two radials and the anal plate are in pairs astride the interbasal sutures. The consolidation of the original pairs of nerves is subject to variation according to the amount of compression in the fused plates, and the external appearance is often greatly modified by the breaking up or reduplication of the ridges; but it seems to be a general rule that primarily there is one nerve cord for each sutural face.

In *Lecanocrinus, Pycnosaccus,* etc., the chambered organ is strongly triangular, and in exceptionally well-preserved specimens we sometimes find the single neural ridge, as in the other cases mentioned, passing externally over the middle of each compound infrabasal.

Since the memoir on the Crinoidea Camerata was written much progress has been made in the knowledge of infrabasals in the Recent crinoids, which were formerly assumed to be all monocyclic, but in which Wachsmuth and Springer predicated the existence of infrabasals upon paleontological evidence. In addition to the discovery of these plates soon afterward by Bury[1] and by Seeliger[2] in *Antedon,* infrabasals have now been found in eight species belonging to the recent genera *Isocrinus, Metacrinus, Promachocrinus* and *Hypalocrinus,* by De Loriol,[3] Clark,[4] Doderlein,[5] Jaekel,[6] and myself.[7]

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[1] Early Stages in the Development of Antedon Rosacea, Philosophical Transactions, London, 1888, p. 288.

[2] Entwicklungeschichte der Crinoiden, Zool. Jahrb., Bd. 6, Morph., 1892, p. 317.

[3] Rev. Suisse de Zool., vol. 2, 1894, p. 494.

[4] Proc. U. S. National Museum, vol. 33, Feb. 29, 1908, p. 671; and Monograph of Existing Crinoids, 1915, p. 316.

[5] Gestielten Crinoiden der Siboga-Expedition, 1907, p. 20.

[6] Sitzungs. Bericht. Gesell. Naturf. Freunde Berlin, 1904, p. 192.

[7] Proc. U. S. National Museum, vol. 36, 1909, p. 187.

Mr. Clark, in the paper cited, said: "It is now known that all Recent crinoids, with the single exception of *Hyocrinus,* are dicyclic"; and in my paper On a New American Jurassic Crinoid above cited, I stated as the accepted conclusion from the researches of authors to that date, 1909, that "there can be no longer any doubt that the Pentacrinidae are all either actually or potentially dicyclic, though in some species the infrabasals are resorbed at an early stage." The last observation had reference to Clark's further researches in 1908,[1] in which he examined 15 specimens of *Isocrinus decorus* and three of the closely related *Endoxocrinus parrae* (*olim Pentacrinus mülleri*). He found infrabasals in all of the former, but none in the latter, in which, however, there is a large hole in the place which they should occupy. This condition is comparable with that which I have found in the species of *Ichthyocrinus* with infrabasals resorbed.

As to the Basals, the one noteworthy fact in the Flexibilia is the frequent great enlargement of the posterior plate in those forms having a well-developed anal side. This occurs in many genera and in all the families,—for example in *Calpiocrinus, Forbesiocrinus, Dactylocrinus, Euryocrinus, Synerocrinus, Amphicrinus,* and all the Taxocrinidae. Among those in which the posterior basal is not materially larger than its fellows are *Lecanocrinus, Mespilocrinus, Anisocrinus, Pycnosaccus, Asaphocrinus* and *Hormocrinus.* In all of the latter the anal *x* is a prominent plate, whereas in those forms with elongated posterior basal the anal *x* has lost its identity as a feature in the calyx. In many of these cases the bulk added by the elongation of the basal is substantially equivalent to that of the vanished anal *x,* and it is a significant fact that if we compare a form like *Lecanocrinus* or *Pycnosaccus* (Pls. I, fig. 34; XII, fig. 10*a*), having a very large anal *x* rising to the height of the radials and a low oblique radianal, with one like *Forbesiocrinus* or *Taxocrinus* (Pls. XXIII, fig. 2; LIII, fig. 2*b*), it will be found that when the radianal is carried upward from its position on the right shoulder of the basal by the enlargement of that plate to the extent of replacing *x,* it will occupy the same position relatively to the basal, but at the level of the top of the radial instead of the bottom.

The elongation of the posterior basal is usually accompanied by a certain asymmetry, so that when this plate is angular distally, as in *Forbesiocrinus,* the right sloping face is the longest (Pl. XXIII, figs. 1*a,* 2, 3), and when it supports a tube-like anal series, as in *Taxocrinus,* the socket in which the series begins is not medially located, but lies more or less toward the right side of the plate (Pl. LIII, figs. 1*a,* 2*b*). Thus the first plate of the anal tube series in both cases, instead of following the basal in direct succession, has usually an oblique position between the right shoulder of the basal and the upper corner of the adjacent radial, representing a late stage in the migration of the radianal in the calyx of the Flexibilia. Striking examples of this character may be seen in numerous figures under the following genera, viz.: *Forbesiocrinus,* Plates XXIII, XXV-XXIX; *Eutaxocrinus,* Plate XLVIII; *Taxocrinus,* Plates LII, LIII, LV, LVII-LX, LXII; *Onychocrinus,* Plates LXVI, LXVII, LXIX, LXX.

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[1] Proc. U. S. National Museum, vol. 35, p. 87.

The form and construction of the posterior basal furnishes the chief ground for differentiation between *Forbesiocrinus* and *Taxocrinus* and the families which they represent, being suturally connected at the distal end with other plates in the former, and only with perisome in the latter.

### *c. Radials and Brachials*

The radials in the Flexibilia are subject to considerable modification, exhibiting wide contrast in form and proportions. They are most prominent in the Lecanocrinidae, in which they are usually the largest, and in typical forms by far the largest plates in the calyx (Pls. I–XV). This disproportion is greatest in *Pycnosaccus* and *Nipterocrinus,* in which the great size of the radials, coupled with the extreme smallness of the succeeding brachials, produces a facies more like that of the Inadunata than of the Flexibilia; in fact it was not until I obtained the proof that the rays in these genera are connected by perisome that their relationship to the latter group became clear (Pls. XI, fig. 9*c;* XII, figs. 2*a, b,* 3*a, b;* XV, fig. 10*b*).

In the Ichthyocrinidae the relative proportions of the plates are exactly reversed, the radials being smaller than the succeeding brachials, so that the ray widens upward like a fan (Pls. XXXII, XXXIX, XLIV). In some species of *Ichthyocrinus,* and in *Cleistocrinus* and *Amphicrinus,* the radials are partly or wholly buried under the column; and in *Calpiocrinus* they are sometimes overgrown by the infrabasals. In the Sagenocrinidae and Taxocrinidae there is no very marked difference between the radials and the lower brachials, the rays being of approximately uniform width. There are occasional exceptions to these rules, as for example *Lecanocrinus bacchus* (Pl. II, figs. 27, 28*a*), in which the ray looks much like that of *Ichthyocrinus;* but in general they furnish a useful guide for the reference of a specimen to its proper family. In *Parichthyocrinus,* which is an intermediate type between the Ichthyocrinidae and Taxocrinidae, the right posterior radial alone is greatly reduced in size by encroachment of the posterior basal, and the primibrach following it is sometimes correspondingly enlarged to a greater size than its fellows (Pl. LXI, figs. 11, 12, 14).

Compound radials are unknown in this group, except in the right posterior ray of those genera having a radianal in the primitive position.

The primary brachials vary in number from one to three or more, the preponderating types being those with 2, or with 3, primibrachs; while the others are exceptional, save in *Onychocrinus* where more than three is a frequent number. As to forms with two or three IBr, there is a marked succession in geological time which has proved to be of importance in the discrimination of genera. The tendency was toward increase in number, so that while 2 IBr was the prevailing plan in the pre-Devonian genera, the 3 IBr plan largely predominated in those of post-Devonian epochs. The first plan includes all the Silurian forms except *Meristocrinus,* and most of the Devonian; it continued through the Carboniferous to the Kaskaskia in the rare genera *Wachsmuthicrinus, Mespilocrinus, Metichthyocrinus, Euryocrinus* and *Synerocrinus,* and recurred exceptionally in one species of *Forbesiocrinus* and in the latest species of *Taxocrinus.* This plan of primibrachs is the one which prevails almost without exception throughout the Camerata; it became predominant in the Mesozoic, and remains so to the present time in the great majority of the Stalked crinoids and comatulids—notable exceptions being *Metacrinus, Calamocrinus,* and *Phrynocrinus.*

The 3 IBr plan, while exceptionally indicated by a few cases in the Silurian and Devonian, became a leading feature in the Carboniferous Flexibilia, where it is conspicuous in numerous species of the widely distributed genera *Forbesiocrinus* and *Taxocrinus,* from the Waverly to the Kaskaskia; in *Parichthyocrinus* from the Burlington and Keokuk; and it continued until the culmination of the group in *Onychocrinus,* some species of which regularly add another primibrach.

This distinction was first pointed out by me in 1906,[1] and it proved to be a very useful character for separating Silurian from Carboniferous species which had all been described under *Taxocrinus;* those with 2 IBr became *Eutaxocrinus,* extending through the Silurian and Devonian and slightly into the Carboniferous. The change from 2 to 3 IBr occurred in the Devonian, where we find the two characters commingled in a single species; and where species of constant 3 IBr type begin to appear. It was a decided morphological change, and it would be interesting to know by what process it was effected.[2]

The number of brachials in the higher divisions is quite irregular, but occasionally it can be utilized in regard to the secundibrachs for specific distinctions.

The articulation upon the distal face of the brachials, and on the proximal face of all but the first, is of a type by itself, different from that of other Paleozoic crinoids; it may be described as an imperfect muscular articulation, with fossae, paired muscles and ligaments, but for the most part without a complete transverse ridge. It is a modification of the straight muscular articulation of the Poteriocrinidae, which also prevails normally throughout the

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[1] Journal of Geology, vol. 14, pp. 487 *et seq.*

[2] This will be discussed by Mr. Austin H. Clark in the forthcoming part II of his Monograph of the Existing Crinoids.

Mesozoic and Recent crinoids with a very few exceptions. It may be comparable to a stage in the senile condition sometimes found in the Recent crinoids, where the transverse ridge becomes obsolete. These articulations are well shown by various figures of *Forbesiocrinus nobilis* on Plate XXIV. Occasionally in the Flexibilia a vestige of the transverse ridge is seen, as in *Lecanocrinus* (Pls. I, fig. 5; II, fig. 3); but in these cases there are no paired muscle or ligament fossae. It will be noted that while in *Forbesiocrinus nobilis* the articulation on the faces of the brachials is as above described, that upon the distal face of the radials is different in not being paired (Pl. XXIV, fig. *7b*). This raises the question whether the so-called radial is homologous with the radial in genera with only 2 IBr, or whether it may not rather be the representative of the lower half of a compound radial, analogous to the radianal. Unfortunately it is impossible to obtain the evidence with which to follow up this question in other genera. It is extremely difficult to obtain disintegrated specimens in which these joint surfaces are clearly shown; the only case in which I have found them being that of *Forbesiocrinus*.

It is now generally accepted by authors that in all crinoids the arms morphologically begin with the first plate above the radials,[1] the latter term being thus restricted to the lowermost circlet of radially situated plates; these plates (Radials) appear at an early stage in the larval crinoid as small points at the angles of the basals and orals (Pl. B, figs. 1-3), and they undergo considerable development before any sign of brachial structures is visible. The plates which finally succeed them in the rays are treated as primary brachials up to and including the first axillary. In some Inadunata, including most of the Larviformia, and occasionally among the Recent crinoids, there is no bifurcation, and the arms are mere continuations of the primary brachials, with no line of demarcation between them. But in the great majority of crinoids, both fossil and recent, the ray divides at some point, usually on the second or third plate. This is the case in all Camerata and all Flexibilia, among which forms with five simple arms are unknown.

The brachials of the Flexibilia, both primary and those of higher orders, are to a large extent characterized by an arcuate curvature of their transverse sutures, which imparts a peculiar aspect to the crown not commonly found in any other fossil group. The proximal margins bend downward in a more or less deep median curve, overlapping the distal margins of the plates next below, which are often hollowed to meet it (Pl. XXVI, figs. *1b, c*). This curvature is usually most pronounced in the distal portion of the arms, appearing in a smaller degree lower down; and sometimes it is entirely wanting. It is least conspicuous in the Lecanocrinidae, where it rarely appears in the visible parts of the rays, the sutures for the most part being perfectly straight. In the later Sagenocrinidae, and in the majority of Ichthyocrinidae and Taxocrinidae, it becomes a most prominent feature in their habitus. *Forbesiocrinus, Ichthyocrinus, Taxocrinus* and *Onychocrinus* are fine examples of the arcuate sutures which continue down to the radials (Pls. XXVI, XXXIII, LV, LVIII, and LXXII). This type of structure was clearly an accompaniment of the great mobility in calyx and arms characteristic of the group. Many Recent pentacrinites have similar arcuate suture lines at the brachial syzygies (Challenger Report on the Stalked Crinoids, pl. 29, fig. 2).

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[1] Mr. Clark is now of the opinion that the radials are not fundamentally true calyx plates, but are structurally more closely related to the ossicles of the brachial series immediately following them; the reasons for this view, based upon the study of the comatulids, will shortly be given by him in full.

When extremely developed, the projecting processes sometimes tend to become fractured, perhaps from contraction at death or during fossilization, thus giving the appearance of separate intercalated plates (Pl. XXVI, figs. 3*b*, 4, 5). This feature has given rise to the idea of "patelloid plates," which has figured to a considerable extent in the literature from Hall, who originated it,[1] to Bather,[2] who treated and figured these apparent plates as a frequent character of the Flexibilia Impinnata. The superficial appearance of many specimens certainly gave good ground for such an interpretation. But by means of entirely isolated plates (Pls. XXIV, figs. 9*a, b,* 17*a, b;* XXVI, figs. 1*b, c*); of weathered specimens in which the sinuous sutures are eroded on the exposed parts while present and distinct in other parts of the same specimen (Pl. LVII, fig. 9); and of grinding, which causes the curves as well as the apparent lines of articulation of the processes to disappear at a very slight depth below the surface (Pl. LXXII, fig. 10);—I have been able to ascertain the actual structure of these parts. This I have illustrated by the accompanying text-figures: 6*a* to *d,* made from a pair of isolated plates, giving dorsal and ventral views; and 7*a* to *c,* cross-sections of three plates in progressive stages of development of the processes, together with the articulating face, *d,* of the most advanced of these three.

From these, as well as from numerous figures on plates above referred to, it will be seen that the projections and their sockets, and the apparent curving of the suture, are almost superficial structures, and that at a short distance inward, as well as at the ventral side of the plates, the sutures are perfectly straight.

To explain the mechanics of the "patelloid" structure, it may be described as consisting of a thin process projecting downward from the middle of the curved proximal margin of the brachials, and occupying a socket of corresponding shape formed for its reception on the distal margin of the apposed brachial. The outer convex surface of the process conforms to the general curvature of the plate, while its inner surface corresponding to the face of the socket slopes toward the outer margin of the brachial, thus making the vertical section of the process triangular and its transverse section lunate. The marginal contact surfaces of the process and socket are crenulated, as contact surfaces usually are. Between their apposed faces there is sufficient space for the dorsal ligament, which perhaps took on an oblique or a nearly horizontal position.

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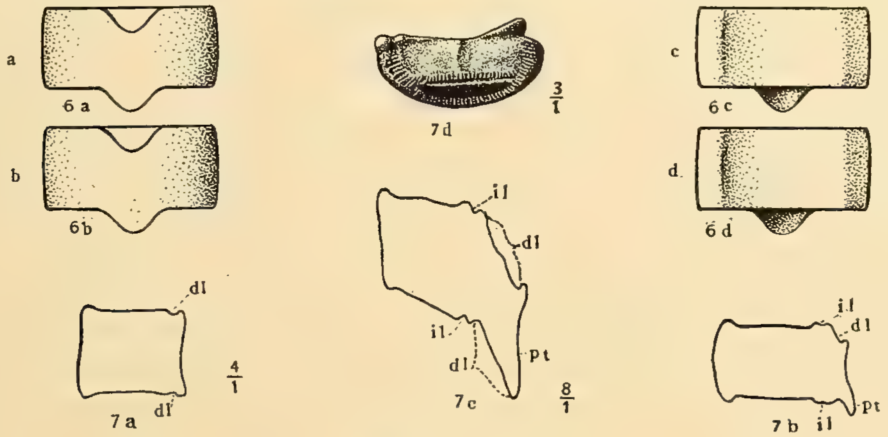
[1] Geology of Iowa, vol. 1, pt. 2, 1858, p. 630.

[2] In Lankester, Treatise on Zoology, pt. 3, 1900, p. 190.

When the arms were folded, the dorsal ligament would be stretched and the process would separate slightly from the socket; but when opened, the ligament would contract and pull the process firmly into the socket. Thus there was an interlocking of the brachials which was probably connected with a stiffening of the crown. The relatively feeble articulations in the Flexibilia, combined with the large size of the arms, would render the latter peculiarly susceptible to fracture in case of contact with a fish or other moving object. With the arms closely coiled, the crown would be compact and in no danger of breakage through an external force; and when extended they would be automatically stiffened by the overlapping of the brachials.



FIGS. *6a-d, 7a-d*

THE "PATELLOID" PROCESSES

*6a, b,* dorsal view of a pair of brachials, showing the projection from proximal edge of upper, and corresponding socket on lower; *6c, d,* ventral view of same, showing perfectly straight sutures. *7a, b, c,* cross sections of three brachials in different stages, showing shallowness of socket and thinness of patelloid process, their progressive development with corresponding enlargement and change in position of the dorsal ligament fossa, and the deepening of the inter-articular ligament fossa; *7d,* distal face of IBr from which the section *7c* was made—a very mature brachial in which the development of the socket and process has proceeded to the extreme, and the structure of the articulating surface has been modified by age; *pt.* patelloid process; *dl.* dorsal ligament fossa; *il.* inter-articular ligament fossa.

## *d. The Arms*

The arms of the Flexibilia are all uniserial, no suggestion of a biserial arrangement being found in the entire group; and they are, as already stated, always multibrachiate, simple arms being unknown. No trace of syzygies has been observed, nor of cuneiform plates, all having parallel proximal and distal faces. In the mode of branching two types prevail: (1) By approximately equal bifurcation, which I call "dichotomous" in preference to "isotomous," because we cannot confine the term to such equally and perfectly symmetrically bifurcating rays as those of the Inadunate genus *Cyathocrinus*. There is a tendency throughout the group to inequality in the branching of the arms beyond the first division, the interval between successive bifurcations being longer on one ramus than on the other; or one may become simple while the other subdivides. So the term must be taken to mean simply that the rays divide by more or less regular bifurcations, as opposed to those in which the branches are given off in the form of lateral ramules markedly smaller than the main trunk; these we call (2) "heterotomous." Under this class we may have unilateral heterotomy, in which the relatively small ramules are restricted to one side of the main ray division, usually toward the inside of the dichotom but exceptionally in one species of *Onychocrinus* to the outer side; *Dactylocrinus* and *Wachsmuthicrinus* are good examples of this type (Pls. XLI, XLIII). Or the heterotomy may be bilateral, where the ramules are borne alternately on opposite sides of the trunks, as in the typical *Onychocrinus* (Pl. LXX). The ramules may divide by nearly equal bifurcation, or by means of secondary ramules.

Between these two principal types there is some intergradation, so that in regard to some forms it is hard to say to which they belong; thus we call *Sagenocrinus* dichotomous, although there is not much difference in principle between a specimen like that of Plate XIX, figure 2, and one of *Lithocrinus* (Pl. XX), which we call doubtfully heterotomous. The two types occur together in the Pentacrinites. *Endoxocrinus* and *Teliocrinus* are strictly isotomous; *Isocrinus* is slightly heterotomous; *Metacrinus* more markedly heterotomous; and *Pentacrînus* almost typically heterotomous. Bather in subdividing the Flexibilia makes the heterotomous arm structure a family character on which he bases his Dactylocrinidae—a group which includes a representative of every one of the four families of my classification. I am unable to attach the same importance to this character, as the two structures occur together in several of the best defined families of the Camerata, as well as in each of the families into which according to my view the Flexibilia are divided.

In one genus of the Lecanocrinidae, *Cholocrinus*, there is a remarkable inequality in the development of arms in the different rays, the two posterior rays and the anterior ray being of ample size, while the two lateral rays are reduced to insignificant dimensions—the two together not occupying half the space of either of the others. This is not a mere individual abnormality, but is constant in four specimens, and is correlated with other characters distinctive of the genus. Unequal rays are found in other groups, especially among the Inadunata including their recent representatives, where the anterior ray is frequently the smallest; and in one singular species, *Cyathocrinus maxvillensis* Whitfield, the two posterior rays are dwarfed. In the Camerata also the lateral rays are occasionally of inferior size. But in none of those groups is there a case where the disproportion is so great as in *Cholocrinus.*

Throughout the group there was a strong tendency in the arms to coil tightly upon themselves over the tegmen (Pl. XXXV, fig. 16). It is very rare to find a specimen with the arms spread out so as to expose the ventral side as often occurs in other groups, except in one species of *Onychocrinus;* even in this, however, it is only the lower parts of the rays that are exposed, the ramules themselves being always tightly folded. Owing to this infolding the arms give an impression of stoutness which is not true in all cases for their distal portions; these are sometimes exceedingly slender.

As a general rule in the crinoids enlargement of the arms is accompanied by reduction in size of the calyx, and *vice versa.* Thus the ponderous arms of *Arachnocrinus*[1] belong to a calyx which is little more than a center of connection between them, while *Hadrocrinus plenissimus,*[2] with almost the largest calyx of any crinoid, is now known to have a great number of short, thread-like arms. Among the Flexibilia the Lecanocrinidae, and to some extent the Sagenocrinidae—*e. g.,* the genus *Sagenocrinus*—have relatively a large calyx and small arms, while the reverse is the case with many of the Taxocrinidae.

Pinnules are entirely wanting in the Flexibilia. Their absence is one of the characteristics of the group. There are ramules in the heterotomous types which may be considered an intermediate stage between pinnules and arms; and in one of the later species of *Onychocrinus,* with ramules branching alternately from every second brachial, there is the nearest approach to pinnulation known in the group; but the resemblance is only slight. That ramules are somewhat different elements from pinnules is indicated by the fact that in some Melocrinidae, and in *Lampterocrinus,* the ramules themselves are regularly pinnuliferous, and they frequently branch on the same principle as arms.

Clark has shown[3] that the free arms of the crinoids are composed of an extension of the boundary between the primarily skeleton-forming dorsal surface and the perisomic ventral surface, so that any series of ossicles on the border between these two surfaces, and composed in equal parts of each, will assume the structure common to all the processes arising in the same region, and will take on from the beginning the structure of the crinoid arm. Thus it is possible to have an interradial arm, such as is found in the posterior interradius of the so-called *Thaumatocrinus renovatus* of P. H. Carpenter, arising just to the left of the anal tube, and in other six-rayed specimens; and where the process is carried to its ultimate conclusion the ten-rayed *Promachocrinus* (*sensu* P. H. Carpenter) is produced.

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[1] Springer, New Am. Foss. Crinoidea, Mem. Mus. Comp. Zool., Vol. XXV, no. 3, 1911, Pl. I, fig. 1.

[2] Wachsmuth and Springer, N. A. Crin. Cam., Mem. Mus. Comp. Zool., Harvard, Vols. XX, XXI, 1897, Pl. XXIV, fig. *2a.*

[3] Journal Washington Acad. Sci., vol. 2, 1912, p. 311.

## II. The Actinal System

### *a. The Tegmen*

The tegmen includes the interambulacral plates or integument of the perisome, which belong to the category of supplementary plates, and logically should be considered under that head; but it seems more convenient to treat the tegmen here as a whole. It consists of orals, ambulacrals, and interambulacrals, out of which open the mouth and anus.

The tegmen of the Flexibilia for a long time was totally unknown and is still very rarely seen; its construction was the subject of much theoretical discussion in former years, which may now be relegated to ancient history.[1] Its true nature was first discovered and described by Wachsmuth and Springer in 1888,[2] in a specimen of *Taxocrinus intermedius* of remarkably perfect preservation, which shows the essential structure completely (Pl. LIII, fig. 1*b*). The great and illuminating feature was the uncovered mouth opening through a pliant disk as in the Recent crinoids, thus differentiating it from that of all other known Paleozoic crinoids, and fixing the systematic position of the group in a way that put an end to the chief speculative discussion concerning it. For it was inferred with much confidence that the structure found in this genus was that of the group throughout—an inference which subsequent discoveries have amply confirmed. A similar tegmen has since been found by me in another species of *Taxocrinus,* and in the genera *Homalocrinus, Cholocrinus, Pycnosaccus, Synerocrinus,* and *Onychocrinus,* representing three out of the four families of the Flexibilia (Pls. VI, fig. 15*b;* IX, fig. 4*d;* XI, fig. 15*b;* XLII, figs. 8*a, n;* LXVII, fig. 7).

The mouth is surrounded by five parted orals, between and below which the plated ambulacra pass inward after traversing the perisome from the arm bases. The orals occupy a relatively small space at the center of the disk, and represent a late stage in the ontogeny of the young crinoid such as was described by W. B. Carpenter in his memoir on *Antedon rosaceus,*[3] where the circlet of orals has detached itself from the summit of the radials on the shoulders of which it was previously superimposed, and is progressively carried inward by reason of the outward expansion of the ring of radials—the space between the two series being now filled in only by the membranous perisome, which is traversed by the five radial grooves (ambulacra) passing out from the peristome between the oral valves to the bifurcation of the arms. The same condition is shown in one stage of the larval *Comactinia* hereinafter described. This condition is also comparable to that of *Holopus* (Pl. A, fig. 8), and of *Thaumatocrinus* (Pl. A, fig. 9*b*), as the orals would appear with some further growth of perisome around them.

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[1] See N. A. Crinoidea Camerata, pp. 88-124.

[2] Discovery of the Ventral Structure of *Taxocrinus*, Proc. Acad. Nat. Sci., Philadelphia, vol. 40, pp. 337-363.

[3] Philosophical Transactions, London, 1866, p. 727.

A more striking parallelism is found in the tegmens of some genera of the family Plicatocrinidae, which has been shown [1] to possess characters approximating those of the Paleozoic Inadunata more closely than any other of the living crinoids. In these forms the orals persist in the adult stage as a central pyramid surrounded by perisomic plates of varying size, some quite large and distinct, thus completely enclosing the visceral mass except for the open mouth and ambulacra. Among these is *Hyocrinus,* which as figured by P. H. Carpenter in the Challenger Report on the Stalked Crinoids, plate 6, has rather large triangular orals, and a lateral anal tube fairly low down at the margin of the disk. *Thalassocrinus* (A. H. Clark, Monograph of the Existing Crinoids, p. 209, fig. 145) has a similar pyramid, with the apex decidedly high, the edges of the orals curiously projecting in thin ribbon-like, sinuous margins which are repeated in the covering plates of the ambulacra throughout the arms; it also has quite large interradials, few in number.

Still more interesting for comparison with our Flexible tegmen is that of the type species of *Ptilocrinus* from the North Pacific, of which I give an original figure (Pl. LXXV, fig. 1*c*). Here not only are the orals with their large connecting ambulacra deeply surrounded by perisomic plates of good size, so that they occupy a relatively small space at the center, but they are somewhat asymmetrical owing to the influence of strong plates surrounding the anal opening, which is rather high up in the interambulacral area.

The orals of the Flexibilia are unequal, the posterior plate being disproportionally enlarged, sometimes almost exceeding in area the other four combined. It is a madreporite perforated by numerous pores, as is shown in *Onychocrinus* (Pl. LXVII, fig. 9*b*), and especially by the perfectly preserved plate in *Synerocrinus incurvus* (Pl. XLII, figs. 8*n, o*); and it doubtless performed the functions of the perforated orals seen in *Holopus* (Pl. A, fig. 8), and in *Hyocrinus* as described by Carpenter (Challenger, Stalked Crinoids, p. 95). The enormous development of the posterior oral does not find a parallel in any of the Recent tegmens, which so far as known are in this respect perfectly symmetrical, save for the slight irregularity in *Ptilocrinus.* But this kind of irregularity is the rule in the orals of the Camerata and the Inadunata.

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[1] Clark, A. H., Jour. Washington Acad. Sci., 1913, p. 494.

Many years after our discovery of the tegmen of *Taxocrinus,* I succeeded in exposing that of *Onychocrinus* in several specimens in a manner which threw additional light upon the structure. It was described and illustrated in 1906,[1] and to the description there given, as well as herein under *Onychocrinus ulrichi,* must reference be had for the full details. The immense size of the posterior oral is emphasized, and the very strong ambulacrals (much heavier than those of *Taxocrinus*) are shown, together with a conspicuous anal tube located close behind the oral. The perisome is extensive, very thin and pliable, thickly studded with very small plates passing far down between the rays, and meeting strong interbrachial plates with which the perisome connects by a well-defined margin of attachment (Pls. LXVI, LXVII, LXVIII). This structure is in every way analogous to that of *Ptilocrinus* (Pl. LXXV, figs. 1*a, b, c*), in which the perisome also passes down between the rays, and in the lower part is studded with strong interbrachial plates, not so regularly arranged as those of *Onychocrinus.* The tegmen of *Calamocrinus,* which has a similar strong interbrachial perisome, represents a stage more advanced than this, in which the orals have been almost completely resorbed, it being difficult to identify them except in a sectional lateral view, where they look like long pegs.[2]

The tegmen of such Flexibilia as *Onychocrinus,* with its wide-spreading rays and flexible calyx, must have been extraordinarily pliant, perhaps more so than in the living crinoids. As found in the fossil, it is always pressed down to the bottom of the calyx cavity so that the connection of the several component parts is not so readily seen in the drawings. Their proper position will be better understood from the restoration (Pl. LXVIII, fig. 6) constructed after careful study of the figured specimens and some others, showing the tegmen as it must have been in life, especially the relation of the anal tube to the perisome, which is always disturbed in the fossil; and also from text-figure 8 showing the relation of the tube to the adjacent calyx plates, and the vertical groove in the margin of the radial to the left caused by pressure of the tube. No description of this tegmen and its appendages could be as luminous and instructive as these restorations, taken in connection with accurate figures of the truly extraordinary series of laboriously prepared specimens illustrated upon the above-cited plates.

The ambulacrals in the few specimens in which they have been seen vary somewhat in form and proportion; in *Taxocrinus* they are short and wide (Pl. LIII, fig. 1*b*), somewhat like those of *Ptilocrinus,* while in *Onychocrinus* they are elongated to a degree not seen in any other crinoid (Pl. LXVII).

The interambulacrals in the Flexibilia consist wholly of small plates forming with the perisome an integument, or plated skin, which supports the ambulacra (Pl. LIII, fig. 1*b*); it occupies the space from the oral pyramid to the margin of the disk, and extends downward and outward between the rays and their divisions where it may connect with well-formed plates which we call interbrachials; usually the distinction between the two is plain, but sometimes they pass insensibly into one another. In either case, however, they are but modifications or extensions of the same element, the perisome; this is primarily a naked skin, but may be partly or wholly studded with calcareous spicules, or with undifferentiated plates, which may become larger or more definite and permanent in the interradial areas; or they may be entirely resorbed, as happens in the tegmen and interrays of most of the living comatulids (See Clark, Monograph of the Existing Crinoids, p. 61, fig. 2; p. 67, figs. 15-19). Their transient existence in these Recent forms represents a stage of development whose fixation paleontologically produced the heavily plated vault of the Camerata, and the solid interradial areas of the Sagenocrinidae. The relations of this element will be further considered under the next head.

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[1] Journal of Geology, vol. 14, 1906, pp. 467 *et seq.*

[2] Agassiz, A., Mem. Mus. Comp. Zoology, Harvard, Vol. XVII, 1892, pl. 6, fig. 7.

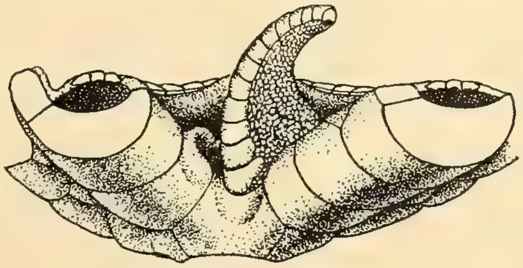

Fig. 8

The anal tube in *Onychocrinus ulrichi;* showing its relation to adjacent parts, and especially the vertical groove in left posterior radial caused by contact and movements of the tube due to the great flexibility of the calyx.

The anal tube in the Flexibilia is formed by the extrusion from the tegmen of the perisome of the posterior interradius, pushed upward by the rectum into a conical tubular protuberance behind the large posterior oral, and usually supported by a vertical row of strong plates on its posterior side only, as is more fully described later in the generic discussions of *Taxocrinus* and *Onychocrinus*. The anus is, according to my view, strictly a tegminal opening, analogous to that of the comatulids, no instance of an opening below the level of the radials being known in this group. The genera *Sycocrinus* and *Cydonocrinus*, which Bather refers to the Taxocrinidae, have such an opening, but I do not regard them as belonging to the Flexibilia. There is in this group no such elevated ventral sac as is found in the Fistulata division of the Inadunata.

## B. THE SUPPLEMENTARY PLATES

### *a. Interradials and Interbrachials*

It was demonstrated by Wachsmuth and Springer[1] that all plates interposed between the rays, from the basals to the orals, whether interradial or interambulacral, belong morphologically to the same element. Hence it follows that if in the growing crinoid certain spicules of the ventral perisome developed into well-defined plates, which remained permanently in a definite position in the axils between the radials or brachials, they would become the interbrachials (or interradials) as we know them; so that whether a certain form has interbrachials or not depends upon the extent to which the spicules in the perisome developed into permanent differentiated plates in the axils. To this statement, however, exception must now be made as to the permanent interradial plates resting upon the basals in forms like *Promachocrinus* and *Thaumatocrinus,* which may develop into arms, and are of different origin, probably more in the nature of reduplicated radials.

The interbrachial structures of the Flexibilia, including those of the posterior side called the anals, undergo a greater variety of modification available for taxonomic purposes than any of the other elements of the crinoid skeleton. Speaking first of those belonging to the regular interradial areas, these structures fall into two categories: (1) The regular strong and fairly well-defined plates that occur in the axils; and (2) the small, irregular plates or granules studding the pliant integument or perisome which lies between the ambulacra and extends from the tegmen in varying degrees and for variable distances down between the rays and their divisions. When in the descriptions we speak of the "iBr" plates, we mean the former.

The two kinds of structures are in many ways entirely distinct in their aspect, and the line of demarcation between them is usually perfectly evident. This is ordinarily the case in the Taxocrinidae, but owing to the condition of the specimens in the fossil state the fact cannot always be ascertained in some of the genera. When the rays are closely folded, the perisome is often pushed inward and thus concealed from view, or is so covered with matrix that it has not been exposed; or if preserved, it is frequently destroyed owing to its fragile nature. This has often led to misconception of the real structure, and to misrepresentation of the facts in illustrations. For instance, it was at one time a matter of dispute whether the genus *Taxocrinus,* as then understood to be represented by *T. tuberculatus* from Dudley, possessed any connection between the rays beyond a possible single plate. Proper cleaning now discloses, in many specimens of that species, the integument of small plates rising high up between the rays and their divisions (Pl. XVI, fig. 5). The interbrachial perisome is well shown in the leading Taxocrinoid genera from earliest to latest; as in *Protaxocrinus* (Pl. XLV, figs. 15, 16), and *Taxocrinus* (Pls. LIII, fig. 3; LVII, fig. 3*a;* LIX, fig. 10). In Plate LVII, figs. 8*a, b,* the perfectly rounded distal face of the strong interbrachials may be seen, and in 6*b* the slight groove is shown for attachment of the perisome, remnants of which are scattered over the disk in figure 6*a* from the same specimen. This was also the case with the earlier *Forbesiocrinus* (Pl. XXIII, fig. 1*a*), and with *Temnocrinus* (Pl. XVI, fig. 5). In *Sagenocrinus,* and the later *Forbesiocrinus,* the solid interbrachials pass high up between the rays and seem to merge insensibly into the tegmen. In *Pycnosaccus* and *Nipterocrinus* there is nothing but perisome between the rays clear down to the radials. In *Lithocrinus* strong interbrachial plates in the lower part of the interradius are isolated by perisome surrounding them. These conditions may be compared with that of the Recent *Ptilocrinus,* in which the rays are separated, from the radials up, by areas of perisome in which a number of good-sized plates appear, rather irregularly distributed (Pl. LXXV, figs. 1*a, b*). With these well-filled interbrachial spaces, the centrally located orals with the posterior one modified by lateral anal structures, and the strong ambulacra—this genus bears a stronger resemblance to a Paleozoic crinoid than any adult Recent form yet discovered.

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[1] The Perisomic Plates of the Crinoids, Proc. Acad. Nat. Sci., Philadelphia, vol. 42, 1890, pp. 345-375.

The function of the interbrachial plates was to fill up spaces between the radial elements as required by the enlargement of the calyx in the growing animal. In rare cases they are limited to a single large plate in each interradius, with the rays arching above it, as in *Anisocrinus* (Pl. X, fig. 3*a*); and there are all variations from that type to the numerously plated areas of *Sagenocrinus* and *Forbesiocrinus.* In the Flexibilia there is no plate of the interradial series, except in the posterior interradius, entering the radial circlet and passing down to contact with the basals as in the Camerate families Rhodocrinidae and Reteocrinidae, and in the living genera *Promachocrinus* and *Thaumatocrinus.* That structure is a phase in the morphology which appears to be unrepresented in this group, save in an isolated species among the later *Taxocrini,* and occasionally in individuals of one or two others.

It was for a long time supposed that the interradials were a structure *sui generis,* belonging almost exclusively to the Paleozoic crinoids. Some traces of their development were found in the course of the researches upon the larva of *Antedon.* Sir Wyville Thomson[1] describes their occurrence as follows:

> In one or two cases, however, I have observed about the time of the first appearance of the anal plate a series of five minute rounded plates developed interradially between the lower edges of the oral plates and the upper edges of the basals. These interradial plates sometimes remain permanent in the mature *Antedon rosaceus,* and they appear to be con-

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[1] Philosophical Transactions, Royal Society, London, 1865, p. 540.

stantly present in some species, as for instance in another and rarer British form, *A. milleri* (Müller). They usually occur, finally, in groups of three or five. They are irregular in form, and they resemble the anal plate in structure and mode of growth.

Dr. Carpenter figures two clusters of these plates as seen at the inside of the calyx;[1] and J. S. Miller shows one such plate in each axil of his *Comatula fimbriata*,[2] which he calls "intercostal plates or joints." In my paper of 1906,[3] after reciting the foregoing observations of Thomson and Carpenter, I said:

> These observations of the so-called interradial plates in *Antedon* have been rather discredited by some subsequent authors in the course of controversial discussions, but I see no reason for questioning them. The occurrences as described seem to me entirely in harmony with the morphology of the group, and if they had not already been seen, I should confidently expect them to be found by further research.

Confirmation of this prediction can now be made in the most striking manner both as to the comatulids and the stalked crinoids. Since W. B. Carpenter's time the existence of a strongly plated interradial perisome extending down to the radials has been shown among Recent stalked crinoids in the genera *Calamocrinus, Ptilocrinus,* and others. As to the comatulids the latest statement is by Clark in his Monograph of the Existing Crinoids, p. 339, as follows:

> In many of the recent comatulids more or less well-defined plates are found between the division series and between the first two or three brachials of the free arms. These may be comparatively small and distinct, or they may be large, forming a solid calcareous plating over the perisome. They are most strongly developed in certain of the large very many armed comasterids, as *Comaster multifida, C. belli, C. typica* and *Comanthina schlegelii;* and though here restricted to small areas between the bases of the $IBr_1$, are very prominent features of certain of the species of *Antedon,* especially of *A. moroccana* and *A. dübenii.*

In young *Comactinia* these plates are well developed, from one to several, subsequently resorbed. In *Promachocrinus* and *Thaumatocrinus* interradials of a very distinct type occur resting on the basals, which apparently have nothing to do with the perisomatic system, but are probably related in their origin to the radials.

It is evident from Dr. Carpenter's figure that these plates are more conspicuous on the interior of the young *Antedon* than at the exterior; in other words, the growth of interbrachials is from within outwards. This accords very well with the observed facts among the fossils of the present group. I have many specimens showing how the interbrachial plates diminish in size and number from the interior of the calyx to the exterior. In many cases where they are well developed on the inside they appear as mere points at the outer surface, and often they do not pass through the wall; so that in a given interradius we may count twice as many plates interiorly as exteriorly (Pl. LXI, figs. 1*a-d; 3a-d*). In some genera which are usually without any such plates a straggling one is occasionally to be seen, and it is quite probable that if we could see the interior of all the specimens, we should find many instances of sporadic plates which have not come to the surface (Pl. XXXIX, fig. 9*b*). It is a fact thoroughly established that these plates multiply with the growth of the individual; but it would seem that in those forms in which the rays are more or less contiguous, and tend to arch over the interbrachial areas, the plates are crowded by the growth of brachials, and are to a certain extent reduced or suppressed at the outer surface of the calyx. In genera like *Taxocrinus, Forbesiocrinus,* and *Uintacrinus,* the variation of the interbrachials with age is very marked, young individuals in some species having none at all, while the adults are profusely supplied (Pls. XXVIII, LV, and Mem. Mus. Comp. Zool. Harvard, vol. 25, no. 1, 1901, pp. 73-85). In *Wachsmuthicrinus,* which has no anal plate, the interbrachials are still more variable, being present or absent in the adult of the same species. In *Nipterocrinus, Pycnosaccus,* and *Cholocrinus* the perisome extends down to the radials as a plated integument, without developing any definite interbrachial plates.

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[1] Philosophical Transactions Royal Society, London, 1866, pl. 33, fig. 7.

[2] Natural History of the Crinoidea, 1821, Frontispiece, Fig. $\frac{2}{l}$G.

[3] Journal of Geology, vol. 14, p. 508.

Notwithstanding the irregularities in some cases as above mentioned, the varying development of the interbrachial plates affords important characters for classification in this group. In some genera the perisome did not pass down between the rays in such a manner as to form any permanent plates in the interbrachial areas; in others they were abundantly developed. Both forms extend from the Silurian to the Carboniferous; the first being characteristic of a little group of genera which may be taken as the typical Ichthyocrinidae—*Ichthyocrinus, Synaptocrinus, Metichthyocrinus,* etc. The tendency in the paleontological history of the group is the same as in the individual, viz., toward an increase of interbrachials. But few forms without such plates are found after the Silurian, while in the Carboniferous their presence in considerable numbers is the general rule. On the other hand, while the latter stage was fully attained in the Silurian genus *Sagenocrinus,* it was the exception in that age.

There is no family in this group in which the rays are completely separated by interradials as in the Rhodocrinidae and Reteocrinidae of the Camerata. But in some of the later species of *Taxocrinus* (Pls. LIX, LX) a tendency is developed for the interradials to pass down and connect by short faces with the basals. Somewhat analogous to this is the isolated occurrence among the Inadunata of corresponding age of a species in which the radials project downward between the basals until they meet the infrabasals (See Wright, Trans. Geol. Soc. Edinburg, X, pt. 1, 1912, pl. 6, figs. 4, 7; pt. 2, 1914, pl. 18, fig. 8).

### *b. The Anal Structures*

Modification of the plates of the posterior, or anal, interradius, taken in connection with the posterior basal, form the basis of the two largest divisions of the Flexibilia; the details of these two plans of structure are fully explained later. A series of further and somewhat parallel modifications occurred under each of the sub-orders, which furnish the characters for several of the genera. The first of these modifications relates to the plate now called by authors generally the "Radianal." The morphological relations of this plate, and its significance in classification, were not understood in reference to the Flexibilia until I pointed them out in my paper of 1902,[1] in which I demonstrated the existence, not before suspected, of such a plate in the well-known species "*Taxocrinus*" *tuberculatus* from the Silurian of Dudley, England, and proposed for it on that ground the genus *Temnocrinus;* and in that of 1906[2] in which I proved the same fact, equally unsuspected, in the Silurian species of *Ichthyocrinus,* and proposed to separate from them the Carboniferous species, in which no such plate is present, under the name *Metichthyocrinus.* Subsequent investigation has abundantly confirmed the conclusions there announced, and has extended them to four other genera, so that the structure of the anal side in the Flexibilia in this respect is now established by a multitude of facts and made perfectly clear.

The term "Radianal" (RA) was first proposed by Bather[3] in 1890 for a plate which is prominent in the development of the anal interradius of the Inadunata. As the name implies, it stands partly in connection with the radial system, in this case with the right posterior radial, and at the same time it functions as a plate eventually leading toward the anal series. How intimate the latter connection is I am now able to demonstrate far more clearly than has ever been done before, as will be seen a little further on.[4]

This plate may be described as occupying four positions, to which may be added by way of a Hibernian concept a fifth, its absence: (1) At the base of the right posterior ray and in contact with the right anterior radial—its primitive and oldest position (*Cupulocrinus, Dendrocrinus,* etc.); (2) under the left half of the right posterior radial, not touching the right anterior, between two basals and meeting the infrabasals (*Thenarocrinus*); (3) obliquely at the lower left of the right posterior radial, resting upon the right shoulder of the posterior basal, and not touching the right anterior,—lower oblique position (*Botryocrinus, Poteriocrinus,* etc.); (4) at the upper left of the right posterior radial, pushed upward on the right shoulder of the elongated posterior basal,—upper oblique position; (5) entirely absent, or perhaps assuming the function of a symmetrically placed anal plate (*Cyathocrinus*). To these might be added for better comparison the condition in which all anal plates are eliminated from the calyx (*Erisocrinus* and *Encrinus*). I have illustrated most of these positions by reference to Inadunate genera; the plate does not occur in the Camerata.

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[1] American Geologist, vol. 30, p. 88.

[2] Journal of Geology, vol. 14, p. 475.

[3] Ann. and Mag. Nat. Hist., ser. 6, vol. 5, p. 329.

[4] My discussion of the position and modifications of the radianal is limited to the Flexibilia, in connection with the development of a corresponding plate in the larval stages of some Recent crinoids, and with illustrations drawn from the dicyclic Inadunata, from which it is now thought the Flexibilia may have been derived. Whether the lower segment (inferradial) of the compound right posterior radial in the Heterocrinidae and allied monocyclic forms should be regarded as homologous with the radianal, as has at times been done by authors (myself included), I shall not undertake here to discuss. The fact that some of these genera have similar compound radials in other rays, and that the true anal series only begins on one face of the axillary superradial, constitute formidable objections to that view. The homologies of this and the anal plate *x*, in the Crinoidea as a whole, will be more fully discussed in a paper entitled "What is the Radianal?" which is now being prepared for publication by my assistant, Dr. Herrick E. Wilson.

There is also the symmetrically situated plate found in all three orders of the crinoids, designated as "Anal *x*," which occurs concurrently with the radianal in many of the genera, and whose exact function or relation is not clearly settled. It has been variously assumed to represent either the first interbrachial of the regular areas; the first plate of the anal tube; or an anal element suddenly introduced. Without attempting to choose between these hypotheses, I shall simply treat it, as I have done heretofore, as a distinct element of the anal structures which may possibly at one stage be replaced by the radianal.

Now in the Flexibilia the radianal passes through precisely the same modifications as above described, in the same chronological succession; and we find that there is in this group a series of generic forms based upon the migration and disappearance of the radianal parallel to that occurring in the Inadunata, and also for the most part parallel as between its own two larger divisions. For we have *Temnocrinus, Protaxocrinus* (Ordovician) and *Ichthyocrinus* (Silurian), like *Cupulocrinus,* with RA directly under the right posterior ray; *Sagenocrinus* and *Homalocrinus* (Silurian), like *Thenarocrinus,* with RA shifted somewhat to the left and located within the basal ring; *Lecanocrinus* and *Gnorimocrinus* (Silurian), like *Botryocrinus,* with RA shifted further to the left and upward to an oblique position under the left lower corner of the right posterior radial; *Lithocrinus, Forbesiocrinus* and *Taxocrinus* (Silurian to Carboniferous), with RA further elevated and resting in a notch formed by the sloping upper corners of the posterior basal and right posterior radial; *Hormocrinus* like *Cyathocrinus* (Silurian to Carboniferous), with RA not identified, there being only symmetrical anal plates above the posterior basal; *Nipterocrinus* and *Metichthyocrinus* (Carboniferous) like *Encrinus,* with all anal plates eliminated from the calyx.

Thus there was in both these orders an evolution from the Ordovician and Silurian to the Carboniferous, in which the radianal passed from the primitive position of a right posterior inferradial by a migration to the left and upward to final complete elimination as a calyx plate in the Carboniferous.

The fact that in some Silurian genera represented by *Sagenocrinus* and *Homalocrinus,* the radianal entered the basal ring through the widening to a variable extent of the right posterior interbasal suture, does not in my opinion alter the conclusion that the order of succession in the migration of this plate was from below upward. The earliest position, viz., that in *Protaxocrinus, Cupulocrinus,* etc., near the beginning of the Ordovician, was at the base of the right posterior ray, and this continued throughout the Silurian. The inclusion of the radianal within the basal circlet, as in *Sagenocrinus* and *Homalocrinus,* may be interpreted as occurring during a process of shifting, not from above downward but from the right toward the median area, in course of which it came into the posterior interray, the line of weakness of the Flexibilia calyx.

This shifting process was in fact an incident of the migration of the plate from the first to the fourth position, during which temporarily and irregularly the two basals—posterior and right posterior—yielding to the influence of the gut pushing from right to left, opened to a varying extent, and admitted a corresponding growth of the radianal in their direction. The great irregularity of this movement is well shown in *Sagenocrinus,* in some specimens of which the radianal rests nearly to its full width upon the infrabasals, in others meets them by only a short line of contact (Pl. XVIII, figs. *2b,* 6), or failing to touch them rests upon the sloping faces of the two basals (Pl. XIX, fig. 5) precisely as in *Lecanocrinus.* This last case is in fact a transition stage affording definite proof that the tendency of the radianal within the limits of the genus itself was really upward. Furthermore, in this genus there is a marked tendency of the interbrachials in all the areas to grow downward as well as upward, so that in a number of instances the first interbrachial is in contact with the basal. Such an irregular downward growth of the radianal cannot therefore be said to represent any well-defined phase of its migration toward the lower oblique position, which became definitely established in several well-marked Silurian genera of the Flexibilia, and thence to the upper oblique position which persisted as a leading character in some of their strongest genera to the close of the Carboniferous.

The position of the radianal in its Carboniferous stage at the upper right of the unsymmetrical posterior basal is shown by numerous examples illustrated upon the plates, both in forms with and without the anal tube. In *Forbesiocrinus* it appears under almost every species—for example Plates XXIII, figures *1a,* 2; XXV, figure 2; XXVII, figure 8—where it occupies a place in the line of least resistance directly above the lower oblique position in such forms as *Lecanocrinus* and *Pycnosaccus,* the space occupied by the large anal *x* in those genera being now filled by the greatly enlarged posterior basal, which has risen to the level of the radials. In *Taxocrinus intermedius,* Plate LIII, figures 1*a*, 2*b*, and *T. ungula,* Plate LV, figure 3, the plate is conspicuous by its large size as compared with the succeeding tube-plates. In many examples of *Forbesiocrinus,* such as Plates XXVI, figure 5, and XXVIII, figures 4, 5, where the equivalent of the row of tube-plates is seen in the vertical series of plates loosened at one side, the line of weakness which invited such a migration is clearly indicated.[1] If now we take the case of *Protaxocrinus* and *Gnorimocrinus,* Plates XLVI, figure 8*b* and XLVII, figure 1, in which the tube plates connect directly with the RA in the primitive and lower oblique positions, we have the whole course of this migration marked by a plain trail.

We are now able to show, as will be pointed out further on, that the same course of migration is followed by a corresponding plate during successive stages of a Recent comatulid, that the trail thus indicated is that of the gut with which the radianal in its earlier and progressive stages was closely associated, and that the phylogenetic development of this character in a Paleozoic group is recapitulated in the ontogeny of the living crinoid. The modifications of the anal interradius as a whole, depending upon its occupation by solid plates or by a tube, are considered under the next head.

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[1] It is of interest to note that in the Camerata there is no such line of weakness—no sloping or leaning to the right, even in the Reteocrinidae, which have a more or less flexible structure.

## THE INTERRELATIONSHIPS OF THE FLEXIBILIA

In my paper of 1906,[1] which as then stated was a note preliminary to the present work, I gave at some length the conclusions to which my investigations had at that time led touching the interrelationships of the Flexibilia; these conclusions remain for the most part substantially the same, and I will restate them here with such additions and reinforcement as subsequent researches have furnished. In attempting to arrange the genera of the Flexibilia in families, or other subgroups, we have to choose for our differential characters between several types of structural modification. At the time of my former discussion the life history of only one genus of crinoids was known, viz., *Antedon*. Considering that to represent, " in a general way and to some extent," the phylogenetic history of the group, I assumed " that its ancestral form would be something like the early larval stage of *Antedon,* with the addition of a radianal, of which no trace or suggestion has as yet been found in the embryological researches on that genus, as I understand them. This would give us a dicyclic crinoid, with a radianal; an anal plate between the posterior radials; two primibrachs, the second one axillary and followed by arm branches; and the ventral side surmounted by a pyramid of oral plates. I have attempted to represent the dorsal side of such a hypothetical crinoid by figure 9 of Plate V" (*op. cit.,* p. 493). I have reproduced the hypothetical figure there given, both for use in this discussion for which it still serves very well,[2] and to show the remarkable way in which it has been confirmed by later discoveries (Pl. A, fig. 7):

First, by the independent researches of Mr. Clark, who in his paper of 1912[3] on the anal plates of the Recent crinoids, and later in his monograph of 1915,[4] says of it:

> In this connection it is most interesting to examine the figure published by Mr. Frank Springer[5] to show the probable primitive structure of the anal interradius and adjacent parts of the calyx in the whole Flexibilia type, both fossil and recent. If we should carry backward to its probable inception the course indicated by the migration of the radianal plate in the young of the recent comatulids, we should arrive at a calyx structure identical with that shown by Mr. Springer and deduced from the study of the fossil forms. From the study of the recent types alone it might be argued that the figure should be slightly modified by the reduplication of anal *x* in the shape of interradials in all the other interradial areas; but from the data acquired from the study of the six-rayed specimens, and the very evident modification of all the recent types in the direction of a perfect, derived from an imperfect, radial symmetry, it would seem that we would be justified in considering these four additional interradials as a later development.

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[1] Journal of Geology, vol. 14, pp. 467 *et seq.*

[2] Although modeled upon *Homalocrinus* instead of the now preferable *Protaxocrinus.*

[3] Jour. Washington Acad. Sci., vol. 2, p. 313.

[4] Monograph of the Existing Crinoids, p. 339.

[5] Jour. Geology, 14, no. 6, 1906, pl. 5, fig. 9; explanation p. 493.

Second, by the evidence furnished by the new researches on the larva of a comatulid of the *Actinometra* type described in a later chapter, showing that the radianal actually begins in the axil between the two basals before the radial is formed, and is thus at the base of the yet undeveloped right posterior ray; from this position, with the development of the radial, the radianal works its way from below the radial and passes upward to the left of it.

Returning now to the form assumed in the hypothetical figure (Pl. A, fig. 7),—the lines of modification from such a form on the dorsal side would be:

*a.* In the radianal, by migration upwards.

*b.* In the anal system, by (1) extension upward in vertical series not connected with brachials, except by perisome; (2) increase upward and laterally in sutural connection with the brachials; (3) elimination of the anal plate by absorption, atrophy, or migration or shifting.

*c.* In the brachial system, by (1) increase in the number of primibrachs; (2) variation in the mode of branching of the higher brachials or arms.

*d.* In the interbrachial system, by growth and multiplication of supplementary plates between the rays.

On the ventral side we might expect modification in the same way that is seen in *Antedon,* viz., a growth of the perisome between the radials and orals, gradually separating the latter plates from the radials and carrying them inward toward the center. This would give the condition found in *Onychocrinus* and *Taxocrinus;* but the cases in which these structures are preserved in the fossils are too few to enable us to trace any of the successive changes.

*a.* The first of the above modifications of the dorsal side has already been discussed; and we are able to trace in the phylogeny of the Flexibilia successive stages in the migration of the radianal, from that shown by the hypothetical figure to that of elimination from the calyx, which form the basis of important generic groups. These stages are analogous to phases in the development of a corresponding plate in the ontogeny of a living crinoid, as above stated.

*b.* The generic distinctions based upon the other modifications of the posterior, or anal, area coming under the second category, are really very striking—more so than can be well expressed in terms of brief analysis. Aside from the matter of the radianal, there are two plans of structure of the anal area which run side by side from the Silurian to the Carboniferous. They start with the primitive anal plate of our supposed ancestral form, and diverge upon the two lines 1 and 2 indicated above.

1. The first of these plans is that which represents a solid support or backing of an anal tube. It is marked by a vertical row of strong, rounded plates, originating on the posterior basal, rising with a very gradual taper to a considerable height between the rays, and having the appearance of a small,

rounded arm; the lower part sometimes rests against the left posterior radial, on which a groove is formed by the continual pressure and movements due to the flexible calyx (text-fig. 8). This armlike series is connected with, or rather seems attached to, the pliant integument filled with small, irregular plates which studded the perisome, or ventral covering, in the group. As I have shown in the tegmen of *Onychocrinus,* the perisome developed between the radials and the orals, carrying the latter relatively inward until, instead of covering the whole ventral side as in the larval *Antedon* (Pl. A, fig. 4), they occupied only a small space in the center of the disk, into which the ambulacra converged after traversing the perisome (Pl. LXVII, fig. 7). In the present modification of the anal side it would seem as if the perisome began to grow with a similar energy between the rays, so that it encroached upon the anal plate on either side as far as the posterior basal; while the upward extension of that plate took the form of a simple vertical series of rounded plates. Hence this armlike row of anal plates is usually found, in well-preserved specimens, connected with the brachials of adjacent rays upon one or both sides by a bordering integument of irregular perisomic plates (Pl. LXVII, figs. *2b, 3b,* 4, 5). This plated integument, in addition to being pliant, was also very fragile, and its preservation in the fossil state is uncertain and irregular.

Sometimes the rays lie so close together that they touch the anal series on both sides, and the bordering integument is thus folded inward so that it cannot be seen from the exterior. Nevertheless, the anal plates usually preserve their rounded appearance, and do not seem to form part of the calyx wall, or to be suturally connected with contiguous rays. Such cases as this give rise to difficulties of interpretation, because there are some forms in which the anal plates rise into a single vertical series connected by suture with the adjacent brachials, and flush with them. These must be distinguished from the cases just noticed, where there is a rounded, armlike row of plates, so closely crowded by the rays that there is neither any part of the integument visible, nor any vacant space on either side, but which were evidently not joined to the brachials by suture. Both cases would answer the description "anals in a vertical series," and yet they undoubtedly represent the two distinct plans, which here, as elsewhere, run into perplexing transition forms.

The armlike row of plates, which are not tubular but on the contrary thick and solid, is the dorsal support of an anal tube formed by the outward growth of the perisome attending the extrusion of the rectum. If in descriptions we sometimes call this row of plates "tube-plates," or the "anal tube," it must be understood as a conventional term—used by many former writers in this sense—to avoid circumlocution, and not as implying that the plates themselves are hollow, or strictly form the wall of a tube.

Now the position of this row of plates shows in a striking manner the effect of that singular influence which, as pointed out by me in 1906,[1] has modified the bilateral symmetry of almost every genus of this entire group. The small infrabasal is almost invariably located under the right posterior ray; the radianal originates under the right posterior ray; it migrates from this position upward until it disappears, but always to the right of the median line; if the arms have an asymmetrical distortion, it is to the right, never to the left. If the posterior basal is angular above, the right sloping face is the longest (Pl. XXIII, figs. *1a, 2*). This vertical series of anal plates is influenced by the same tendency, and the position of its lower plate probably represents one of the later stages of the radianal. The posterior basal on which it rests is excavated into a shallow socket, like the articulating facet of a radial, on the right shoulder of the plate, so that we usually see a small tongue or angle of that plate rising up to the left of the base of the anal plate higher than to the right (Pls. LII, fig. 10; LIII, figs. *1a, 2b*). This asymmetry in the position of the socket-like excavation is variable in degree, but even where by reason of pressure of the adjacent rays the tube appears to be median, careful examination will usually show that the exposed part of the basal is slightly widest at the left. Not only so, but the anal series itself, even when the lower plates touch the left posterior radial, eventually leans to the right, so that the vacant space, or the plated integument if it is preserved, is always widest at the left; and the anal plates are sometimes found firmly cemented by pressure to the side of the right posterior ray, leaving no other plates visible at that side, thus giving an appearance of sutural union which must be guarded against in studying these fossils.

The shape and position of this anal row of plates are subject to much variation owing to pressure in fossilization, but the dextrorse asymmetry is almost the invariable rule. This is due to the line of weakness at the right of the posterior interradius which is followed by the radianal in its upward migration.

After citing the foregoing statement from my paper of 1906, in the discussion already referred to,[2] Mr. Clark says:

> In the ontogeny of the comatulids the radianal follows the same course as in a succession of fossil genera; the anal tube is always to the right of the median line of the posterior interradius; that the supplementary arm arising on anal *x* in the young of *Thaumatocrinus renovatus* and of *Promachocrinus kerguelensis* does not turn to the right is to be interpreted purely as a secondary condition, the result of its origin on the edge of the disk and its free extension outward from the body. Were the series of ossicles following anal *x* in the young of *Thaumatocrinus* and *Promachocrinus* incorporated in the perisome, we cannot doubt but that it would have followed the anal tube in its migration to the right, and would, therefore, have come into complete correspondence with the conditions seen in the fossil Flexibilia.

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[1] Journal of Geology, Vol. XIV, p. 496.

[2] Monograph of the Existing Crinoids, 1915, p. 332.

This plan of anal structure began in the Ordovician, and is found in the Taxocrinoid genera from *Protaxocrinus* and *Gnorimocrinus* in the Trenton and Silurian, to *Taxocrinus* and *Onychocrinus* in the Carboniferous, surviving until the Kaskaskia. Being thus so characteristic of that series of genera, it may well be called the *Taxocrinus* plan. It has persisted to the present time, as shown in the early stages of *Antedon, Comactinia, Promachocrinus,* etc., in which a plate directly connected with the tube is progressively developed, while in the adult of these forms, and of *Calamocrinus, Ptilocrinus, Phrynocrinus* and *Thallassocrinus,* plates of anal origin have completely disappeared from the dorsal cup.

2. The second plan is that of a simple extension of the anal system by the addition of other plates of a solid nature similar to that of the original plate. These plates are joined by sutural union to the adjacent plates of the posterior rays, and also with each other; so that as far as they extend upward they are incorporated into the calyx walls in the same manner as the plates of the other interbrachial areas. The posterior basal is either simply truncate, followed by one plate; angular, followed by two plates; or truncate with sloping shoulders, followed by three plates; but in each of these cases all the plates, and others of a similar nature succeeding them, form by sutural union (of course of the loose order characteristic of the whole group) part of the calyx wall.

This form of anal structure existed from the Silurian to the Carboniferous. The primitive stage is found in such genera as *Lecanocrinus* (Pl. I, fig. 34), and *Anisocrinus* (Pl. X, fig. 3*b*), in which the posterior rays arch over the anal plate, leaving no vacant space above it. In *Calpiocrinus* we see its simplest extension by the addition of single plates in succession (Pl. VIII, fig. 2*b*). In *Temnocrinus* we have a further modification by the addition of two or three plates abutting on the anal (Pl. XVI, figs. 4, 5). The development was rapid, for in another Silurian genus, *Sagenocrinus,* in which the dextrorse asymmetry caused by the presence of a radianal is still a feature, we have a perfect example of this plan in its fullest extension, where the anal area, following upon an angular posterior basal, is completely filled to the height of several orders of brachials with solid plates forming a regular continuation of the calyx wall. Because of its remarkable development in that genus this form of anal structure may appropriately be called the *Sagenocrinus* plan. It is carried forward with equal perfection into the Carboniferous by the genus *Forbesiocrinus,* in which the radianal has risen to the upper oblique position; and it persists through the Keokuk and Warsaw to the Coal Measures.

While there are some genera from the Silurian to the Carboniferous in which the calyx seems to be bilaterally symmetrical, yet it is a fact that the dextrorse asymmetry remains as a general characteristic of this form as well as that of the *Taxocrinus* plan. If the posterior basal is angular above, the face sloping to the right is generally the longest, and the series of plates following it a little the largest (Pl. XXVII, fig. 8); if it is truncate and followed by one large plate which is angular above, the same remark may apply to the second plate. Among such genera as *Calpiocrinus, Temnocrinus,* and *Sagenocrinus* there are considerable variations of this plan; but throughout its entire range—except in certain peculiar transition cases to which I will allude later—there is no suggestion, in the external form of the cup, of any such structure as an anal tube.

Under this form, as well as the first, the modification reached the phase of the entire disappearance of the anal plates, first in the Silurian without disturbing the radianal, as in *Ichthyocrinus,* and afterwards in the Carboniferous with complete elimination of that plate, as in *Metichthyocrinus.*

Looking at these well-marked examples of the two plans, one cannot fail to be impressed with their complete distinctness as they stand side by side in the Silurian (Pls. XVIII and XLVII), and in the Carboniferous (Pls. XXIX and LIII). They run a somewhat parallel course during the greater part of the paleontological history of the group. The *Taxocrinus* plan, beginning first, maintains a vigorous course to its culmination in the Kaskaskia in the genera *Taxocrinus* and *Onychocrinus;* while the *Sagenocrinus* plan, starting later, culminated in the Keokuk and Warsaw groups, although continuing with a degenerate form into the Coal Measures. The former is thus the one character connected with the anal structures which survived from the Ordovician almost to the extinction of the group in the Carboniferous, and is still represented in the larvae of the existing forms.

Notwithstanding the evident distinctness of the two plans, their early divergence from a common origin which can with reasonable probability be inferred, and their long duration as independent lines of structure, it is nevertheless a curious fact that they also tend to run together, in a sort of convergent evolution, toward the close of their history. I can show most beautifully by actual specimens how this has occurred in the Carboniferous between *Forbesiocrinus* and *Taxocrinus,* not so much in the way of individual variations as in the modification of species. We have a species of *Forbesiocrinus* in the Keokuk limestone with a firmly plated anal area, in which there is a well-marked vertical series imbedded in the middle, but usually starting on the longer right shoulder of the basal (Pl. XXVIII, figs. 4, 5). On the other hand, there is in the same formation, and at about the same horizon, a form of *Taxocrinus* in which, while the anal series is rounded and prominent, and merges plainly into the perisome above, the plates of the bordering integument, though still movable, are strong and heavy, and apparently united to the adjacent brachials by loose suture (Pl. LIX, figs. 2, 3, 4). In this the modification begun in the last case has evidently been carried to a phase in which the strong structures composing the *Forbesiocrinus* plan have broken down in the anal area and given place to the opposite one. It thus happens that we are sometimes in doubt to which of the two genera a species ought to be referred; and much of the confusion and shifting of opinion as to the relations of these genera is traceable to the failure to take proper account of these transitional forms.

There was a sort of struggle for existence between the two plans, and it would seem that the group adhered in the end to that structure which was in best accord with its flexible characteristics; and we may perhaps infer that the *Sagenocrinus* plan, which tended more in the direction of the Camerate structure, was finally extinguished by reversion to the other. This was almost accomplished in the Kaskaskia, where there is a species, *Taxocrinus whitfieldi* Hall, which has the habitus of *Forbesiocrinus* in everything except the anal side, where it is a perfect example of structure No. 1 (Pl. LX). In fact, the general character of the *Taxocrini* in the St. Louis and Kaskaskia limestones is that of a strong interbrachial structure in the regular areas, combined with a weak and flexible one in the anal area containing the conspicuous tube and its bordering integument. In the latest surviving genus of the Sagenocrinidae, *Amphicrinus,* which continues into the Coal Measures, there is a similar tendency. Not only is the anal interradius persistently narrower than the others, but it shows signs of breaking down through some instability of the lower plates which appears in nearly all the specimens (Pl. XL, figs. 9*a, b*).

In the family Lecanocrinidae structure No. 2 in its earlier stages was the prevailing type, viz., one large anal plate, with perhaps the addition of a few similar ones above it, completely filling the area. In *Lecanocrinus macropetalus,* from the Niagaran group at Lockport, New York, we have a most characteristic example of this family—a rounded, ovoid crown, with a perfectly even surface, the rays and arms flat dorsally and in close contact throughout (Pl. III, figs. 1 to 19). It has a single very large plate rising above the level of the radials, and curving to a point between the rays, which abut upon it at either side and close over it in an arch. This plate is without depressions of any kind, and is entirely flush with the general curvature of the crown. In certain other species from the same locality and horizon, now referred to the new genus *Asaphocrinus* (Pl. IV), this plate begins to be depressed at the sides from the upper end down, so as to leave a ridgelike elevation in the middle quite resembling the base of our so-called anal tube, while the full dimensions of the plate are still retained. In some specimens of these forms we can see this median ridge continued by a second small rounded plate of the same form and size, the large anal having lost its pointed angle and become truncate to support this new plate. Here we have the beginning of the armlike anal series. If the process is pushed a little further, so that the depressed lateral margins of the large anal plate become replaced by perisome, we shall have a complete *Taxocrinus* anal side, and our *Lecanocrinus* will have been transformed into a *Gnorimocrinus*. It is now very curious that the tendency is actually in this direction in regard to those other characters on which the two families have been separated; for along with these changes in the anal plate there appear marked depressions between the rays and their divisions, which become rounded, with strong tendency to divergence in the upper portions, and to long and delicate arms. I have described this as a modification from *Lecanocrinus* toward *Gnorimocrinus*. Of course, we do not know which way it really was, and it is quite possible that the process of modification was in the opposite direction.

Which of these two plans was the primitive one we cannot determine from their paleontological history, as they both doubtless run far back into the obscurity of pre-Ordovician epochs. The earliest known species of undoubted Flexibilia type—*Protaxocrinus elegans* and *P. laevis* from the Trenton limestone—have the *Taxocrinus* anal side; and, as I shall show later on, the type was clearly derived from the Inadunata. The opposite anal plan, which is that of the Camerata, is represented in *Cleiocrinus* from the same horizon, which is perhaps a transition form with some flexible and some cystid characteristics. There is, however, to be considered the question whether the morphological differences which gave rise to this structure have not continued to the present time in some of the Articulata; and we may, in that connection, venture an opinion as to their probable origin.

Many of the modifications in the external form of the calyx were undoubtedly due to differences in the position of the anus. If the gut issued from the visceral mass laterally, and remained there, the growing skeleton would not be greatly affected by its position, except in the production of bilateral symmetry by the tubelike structure. If it issued ventrally, and from the center of the disk at an early ontogenetic stage, the skeleton would not be influenced by it at all, but should have perfect pentamerous symmetry. Between these two extremes there would be a wide range of variation in the outward form and arrangement of the anal side. And we may suppose that as the anus shifted from a very low, lateral position toward the margin of the disk, a series of tube plates would appear and gradually increase in number until the tube should become a distinct structure, or should lose its distinctive character by becoming suturally united to the rays with or without the intervention of other plates, like those of the other interbrachial areas. By the time the anus had moved well into the central part of the disk, where lateral support was unnecessary, all plates of the anal series would be eliminated from the skeleton. Such shifting in the position of the rectum is a fact well known in the embryology of the Echinoderms,[1] and it may be remarked that there are instances, both among the Camerata and the Inadunata, where the anus passed out through the test below the level of the arm-bases. A review of our knowledge of this movement of the rectum in the Recent crinoids will be useful at this point.

Until recently, the only crinoid the larval stages of which we knew was *Antedon,* which has been the subject of elaborate and splendid researches by several distinguished and able investigators. The course of development of the anal plate in the larva of *Antedon,* as brought out by the works of these eminent men, lends force to the above suggestion.

Sir Wyville Thomson's account[2] of it is as follows:

> About the period of the development of the second radials, a forked spicule makes its appearance in one of the interradial spaces between the upper portion of two of the first radial plates. This gradually extends in the usual way till it becomes developed into a round, cribriform, superficial plate. Simultaneously with the appearance of this "anal" plate, a caecal process like the finger of a glove rises from one side of the stomach and curves toward the plate. The plate increases in size, becomes enclosed in a little flattened tubercle of sarcode, and maintaining its upright position it passes slightly outwards, leaving a space on the edge of the disk between itself and the base of the oral plate immediately within it. Towards this space the caecal intestinal process directs itself. It rises up through it in the form of an elongated tubular closed papilla. The summit of the papilla is finally absorbed, and a patent anal opening is formed.

And further, on p. 540:

> Upon the appearance of the second and third radial joints, the perisome between and somewhat above two of the first radials rises into a rounded papilla, towards which a caecal process of the digestive cavity is directed. On the outer side of this papilla a branching spicule appears which rapidly extends into a round plate. This, the anal plate, grows, and afterwards thickens precisely on the model of the basal and oral plates.

Dr. W. B. Carpenter continued the researches begun by Sir Wyville upon the development of *Antedon rosaceus,* and he has given,[3] with most admirable illustrations, the complete history of the anal plate. For convenience I reproduce a few of his figures—some on a different scale of enlargement—which will assist me in explaining the thought I have in mind. In quoting some parts of Carpenter's description, I refer to the figures on my own plate instead of to his original numbers. He gives the following statement of the first appearance and subsequent history of this plate (p. 727):

> Between two of the radials, and on the same level with them, an unsymmetrical plate early shows itself, the subsequent relation of which to the vent proves it to be an *anal* plate (Pl. A,

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[1] Bury, H., Early Stages in the Development of *Antedon rosacea;* Philosophical Trans. Roy. Soc. London, Vol. 179 B, 1888, p. 294.

[2] On the Embryogeny of *Antedon rosaceus,* Philosophical Trans. Roy. Soc. London, vol. 155, 1865, p. 529.

[3] Philosophical Transactions Roy. Soc. London, 1866, pp. 671 ff.

> fig. 1). . . . . Simultaneously with the appearance of the anal plate, a slender digitate process rises from one side of the stomach and curves towards that plate; this constitutes the rudiment of the Intestine.

This is at a very early stage. At a more advanced stage, shown by figures 2, 3, Plate A, the account proceeds:

> The single anal plate originally interposed between two of the first radials (RR), being attached not so much to the neighboring plates as to the visceral mass, begins to be lifted out (as it were) from between them with the development of the anal funnel; and the space left by it is partly filled up by the lateral extension of the two radials between which it was previously interposed, but which do not yet come into mutual contact (p. 732).

And further:

> The anal funnel (Pl. A, fig. 2) is now a very conspicuous object, the anal plate (*x*) which it bears on its outer side being altogether lifted out from between the two first radials which it originally separated (p. 734).

The anal plate finally disappears altogether before the adult stage is reached, and the anus takes up its permanent position toward the margin of the disk.

An important fact not stated by either of these authors, but which clearly appears from Dr. Carpenter's figure (*op. cit.*, pl. 41, fig. 1), is that the anal plate does not abut upon the two radials equally, but has a closer relation to the right posterior radial, whose margin is inwardly curved for its accommodation. In Sir Wyville Thomson's figure showing the position of the anal plate and the caecal process from the stomach towards it (*op. cit.*, pl. 27, fig. 1), the plate is represented as closer to the left posterior radial, and the intestine as curving to it from the left of the posterior interradius. This is contrary to all other observations of this plate and of the intestine, and leads to the suspicion that the figure may have been reversed in lithographing.

The position of the anal plate in the same genus is also shown by Sars,[1] and its migration, as deduced from the works of the foregoing authors, is illustrated by Bather in the Lankester Zoology, p. 122, Figure XXX, in which he has also shown the plate as abutting upon the radials by straight sutures, instead of encroaching upon the one to the right by a curved margin.

In later years Dr. Th. Mortensen, of Copenhagen, has made important studies of the pentacrinoid stage of an Antedonid from Greenland, *Hathrometra prolixa,* in which the position of the anal at the left of the right posterior radial is shown by an interesting series of figures.[2] As in *Antedon bifida* (*rosaceus auctt.*), the plate is first observed after the radials and incipient brachials have formed (*op. cit.*, pl. 9, fig. 3). Mortensen's observations are of particular value because his specimens were found in broods attached to the cirri of the parents, and he had before him several developmental stages; from his Stage I (pl. 9, fig. 1), in which the calyx consists only of basals and orals with no trace of radials, to Stage IV (fig. 4), in which the radials and brachials have become well established, and the anal plate is distinct—cutting into the left side of the radial by a curved border; and finally to Stage V (fig. 5) in which the radials have formed a closed ring and the arms have begun to branch. It is clearly shown by this independent material of an additional species of Antedonid, living remote from those previously investigated, that the so-called anal plate in that genus does not appear until after the radials are well under way, and then in a concavity at the left side of the right posterior radial. This is in complete agreement with the order of appearance of the plate as seen by W. B. Carpenter, Thomson, and Sars in two other species of the Antedonidae; and it is therefore probably the general rule in the family.

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[1] Mémoires pour servir à la connaissance des Crinoïdes Vivantes, 1868, pl. 5, fig. 3.

[2] Report Echinoderms collected by the Danmark-Expedition at Northeast Greenland, 1910, p. 242; pls. 9, figs. 1-5; 11, figs. 1, 5, 6; 12, fig. 5.

The most recent investigations upon the pentacrinoid larva of the comatulids are those of Mr. Austin Hobart Clark, whose extensive researches upon the Existing Crinoids, embracing collections of world-wide distribution, have given him unprecedented facilities for observation of structural details in specimens at different stages of growth. The results of his studies upon the so-called anal plate in the Recent forms throw important light upon its position and relations.[1] He has examined "many hundreds of pentacrinoid larvae belonging to numerous species distributed in several families." Based upon these observations he gives the following account of the course followed by the anal plate during successive stages (quoting from the monograph, p. 331):

> In *Antedon* the so-called anal plate is formed, at about the period of development of the $IBr_2$, between the two posterior radials; but it is noticeable that while the radial to the left of it is of normal shape that to the right has its left side more or less cut away for its reception. When the " anal " is lifted out from the circlet of radials just previous to its resorption it is noticeable that it keeps to the right of the posterior interradial area, remaining more or less in contact with the right hand radial and first primibrach instead of being drawn directly upward, as would be expected; also the right radial is asymmetrical, more convex on the right side than on the left (adjoining the " anal "), though after the withdrawal of the " anal " this asymmetry quickly disappears.
>
> The general tendency of the " anal " plate (of the young *Antedon*) to keep to the right of the posterior interradial area, though very strongly marked, does not appear ever to have attracted attention; but it is nevertheless a fact of the very highest importance.
>
> In the young of *Promachocrinus*, in which the five infrabasals are large and equal in size, the " anal " appears to be formed before any of the radials, occupying a position in the rhombic area between the corners of the basals and orals. Soon afterward the radial appears, just to the right of and in line with it, between the basal and oral of that side and to the right of the vertical line dividing the basals and orals. The radial grows much faster than the anal, which it gradually surrounds, so that the latter comes to lie in a deep concavity in the side of the radial to the right of it and to the right of the posterior interradius, well to the right of the midline of the posterior basal. Later this right hand radial extends itself beneath the

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[1] On the Homologies of the so-called Anal and other plates in the pentacrinoid Larva of the free Crinoids, Jour. Washington Acad. Sci., vol. 2, 1912, pp. 309-314; Monograph of the Existing Crinoids, 1915, pp. 331-339.

"anal" and the concavity becomes straightened out and disappears, the "anal" concurrently being shoved diagonally forward (toward the left) and disappearing by resorption.

After noting that in certain fossil groups there may be traced a progressive variation in the position of the radianal from a primitive position under the right posterior radial to an oblique position under the lower left-hand corner of the radial, and finally to complete elimination, as shown by my paper of 1906, he continues:

> The position of the so-called "anal" in the larvae of *Promachocrinus,* lying within a concavity in the lower left hand portion of the radial to the right of the posterior interradius, and its migration upward and toward the left, leave no room for doubt that the so-called anal of the pentacrinoid larvae is nothing more nor less than the radianal of the fossil forms (p. 332).

He then discusses the case of *Thaumatocrinus renovatus* P. H. Carpenter, with its anal tube and a vertical series of plates to the left of it arising from an interradial in the posterior interradius (Pl. A, fig. 9*a* herein), and shows that Carpenter's specimen was the young stage of the normally 10-rayed *Promachocrinus abyssorum;* that the series of plates above mentioned represents an arm similar to what he (Clark) has observed in some thirty 6-rayed specimens. His observations on this point are as follows (p. 338):

> The interesting *Thaumatocrinus renovatus* is the young of the species later described as *Promachocrinus abyssorum* (with which it was found associated) just after the resorption of the radianal and the formation of all of the interradials from which the five additional arms are commencing to grow. The posterior interradial arm as seen in the so-called *Thaumatocrinus* is the first to form, and is consequently larger than the others; but from the size of this posterior arm and the breadth of the interradials I suspect that smaller arms borne on the other interradials have been lost, as these interradial arms when small are extremely delicate. During growth the posterior interradial arm of *Thaumatocrinus* becomes reduplicated on all the other interradial plates, and all of the five interradial arms gradually increase to the size of the five primary arms (the extensive plating of the disk at the same time disappearing by resorption) so that the 10-armed *Promachocrinus abyssorum* results.
>
> Anal $x$ in the fossil forms may be reduplicated in the form of a series of interradials, one in each of the interradial areas, and therefore, bearing in mind the greater perfection of the radial symmetry in the recent types, it does not surprise us to see the same thing in the recent comatulids. In some thirty 6-rayed specimens which I have studied the supernumerary ray is in all cases but two inserted behind the left posterior—that is, between the two posterior radials and receiving its ambulacra from the groove trunk to the left. It is impossible to interpret this otherwise than as the persistence and subsequent development of anal $x$ in types in which the interradials, including anal $x$, are normally resorbed immediately after formation, exactly as it is developed in *Promachocrinus* and *Thaumatocrinus.*

It is important to note, with reference to the development of the so-called anal plate in another family already alluded to and hereinafter to be described in detail, that according to all the foregoing statements the plate in *Antedon* is not developed until after the radials have formed and the primibrachs have begun to appear.

From the foregoing observations we see that the position and movements of the anal plate are not governed by its connection with other plates of the aboral side, but that they depend upon the shifting and development of the gut, to which it is at an early stage attached. And we can readily trace in the movements of the plate thus indicated striking analogies to some of the anal conditions observed among the paleozoic genera.

Now we have in two great living types of the comatulids just such differences in the position of the anus—though in less degree—as we have supposed to occur among the ancient forms; viz., that of *Antedon* being excentric, while that of *Comactinia, Comanthus* (*Actinometra*), and their allies, is substantially central. The excentricity of *Antedon,* while producing an anal plate in the larval skeleton, is not sufficient, or sufficiently persistent, to affect the form of the calyx in the adult, which in both types has perfect pentamerous symmetry.

We may also be warranted in supposing, from the observed course of development of the anal structures in the larva of the comatulids as above described, that the *Taxocrinus* plan represents the earliest and most primitive form, and that the modifications of this in paleontological time were those which tended toward the disappearance of the row of anal plates, with its border of perisome, and the substitution for a time of regular calyx plates suturally connected with the adjacent rays as in the Camerata. Hence the final outcome of the struggle from Paleozoic to Recent time was the survival of the original plan, and the suppression of the modified one.

3. The third modification of the anal structures is that in which the anal plate has altogether disappeared, and it is merely a further extension of one of the preceding. This was accomplished in the Carboniferous, where in the genus *Metichthyocrinus* we have a crinoid with perfect pentamerous symmetry, so far as the external skeleton shows. A genus in the Devonian, *Synaptocrinus,* reaches this stage, and two others in the Carboniferous—*Wachsmuthicrinus* in which traces of bilateral symmetry can be seen in the slightly larger size of the posterior basal, and *Nipterocrinus* in which the pentamerous symmetry seems to be perfect. This modification apparently did not greatly influence the history of the group.

*c.* The first modification in the brachial system—*i. e.,* in the number of primibrachs—has already been described and discussed as to its details. There can be little doubt that the primitive form in this respect was that with two primibrachs. It is that of the comatulid larva, and it prevailed almost exclusively in the Silurian. The few cases in which there is but one primibrach may be explained by the syzygial union of two of the primitive brachials, just as happens in some species of the living *Antedon,* without changing the fundamental plan. The addition of another primary brachial simultaneously in all of the rays, producing the 3 IBr structure, cannot be explained in any such way, and the occurrence of this form in the Silurian is so limited and exceptional that it may scarcely be said to have had a beginning before the Devonian. It is clearly the successor of the first one in the Paleozoic. The 2 IBr structure continued from the Ordovician through the Devonian and Carboniferous, with constantly diminishing importance. The 3 IBr structure, on the other hand, having barely made a beginning in the Silurian, shows a steady increase through the Devonian and Carboniferous, and prevailed exclusively in the Warsaw, St. Louis, and Kaskaskia in the genera *Forbesiocrinus, Taxocrinus,* and *Onychocrinus,* with a slight tendency in *Taxocrinus* of the Kaskaskia to reversion to the original form. In the latest and most extravagant genus of the group, *Onychocrinus,* it shows a tendency to further development by the addition of another brachial, not sporadically but constantly as a well-defined character among species. From the tenacious grip that this structure had upon several of the strongest genera it must be regarded as a morphological change of much importance, strongly affecting the phylogenetic history of the group; but yet subordinate, in my opinion, to the great differentiation of the anal structure, and therefore not available for defining large divisions.

The second brachial modification is marked by interesting changes in the mode of branching of the rays above the first axillary, from a more or less regular division of the rays by successive bifurcations—dichotomy—to one into large main branches, or arm-trunks, bearing ramules on one or both sides—heterotomy. Both were established in the Silurian, and continued through the Devonian and Carboniferous, and were in force, side by side, in the genera *Taxocrinus* and *Onychocrinus* at the close of the Subcarboniferous in the Kaskaskia. The dichotomous plan, which was probably the primitive one, was by far the most prevalent throughout; and the heterotomous plan was a modification which, while it ran parallel to the other to the end of the group, did not supplant it. The differences arising out of this modification afford very good characters for generic distinction.

*d.* The modifications in the plates of the interbrachial areas might properly have been considered in connection with those of the anal side, inasmuch as they all belong to the system of supplementary plates as distinguished from that to which the brachials belong. Sir Wyville Thomson was led by his researches on the embryology of *Antedon*[1] to regard the skeleton of the crinoid as composed of two systems of plates, which he states to be thoroughly distinct in their structure and mode of growth. These he designated as the Radial, and the Perisomatic, systems of plates. The former is distinguished by being chiefly made up of a peculiar fasciculated tissue of parallel rods, while the latter commence as simple cribriform films imbedded in the outer layer of the perisome, and thicken by a repetition inwards of the same diffuse areolar tissue. The Radial system he considers to include the joints of the stem, the centrodorsal plate, the radial plates, and the plates of the arms and pinnules, or brachials. To the Perisomatic system he refers the plates sometimes seen between the second radials, and any other plates of the cup or disk. Dr. Carpenter,[1] while not agreeing altogether with Sir Wyville as to the grounds of differentiation of these plates, substantially recognizes the two systems of Radial and Perisomatic plates as defined by him, except that he ranks the basal plates with the former instead of the latter.

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[1] Philosophical Transactions Roy. Soc. London, 1865, p. 540.

As before stated, Wachsmuth and Springer divided the plates of the crinoid skeleton into *primary* and *supplementary* plates; the former including the stem ossicles, infrabasals, basals, radials, brachials, orals, and ambulacrals, and the latter the anal, interbrachial, and interambulacral plates. According to either of these groupings of the plates the anals and interbrachials fall under the same category. It was also demonstrated by Wachsmuth and Springer[2] that all plates interposed between the rays, from the basals to the orals, whether interbrachial or interambulacral, belong morphologically to the same element. Hence it follows that if in the growing crinoid certain spicules of the ventral perisome developed into well-defined plates, which remained permanently in a definite position in the axils between the radials or brachials, they would become the interbrachial (or interradial) plates as we know them; so that whether a certain form has interbrachials or not depends upon the extent to which the perisome has developed between the rays and their divisions. The influence of the varying development of these plates upon the classification of the group has been sufficiently discussed in the chapter on Morphology.

There is another modification not suggested by anything apparent in the primitive type, but affecting the general form and habitus of these crinoids in a way that is of considerable practical importance. Anyone who has had occasion to arrange the fossils of this group cannot help being struck by the presence of two general types. One is marked by the tendency of the calyx and arms to form a globose, ovoid, or pyriform crown, in which the arms lie in close contact—although in some genera the lower part of the rays are separated by wide interbrachial areas, above which they come together again. In the other, on the contrary, the tendency is toward a spreading crown, caused by the increasing divergence of the rays upward. In the first the plates of the rays and arms, and the intervening interbrachial structures when present, are for a considerable distance up more or less flush with one another exteriorly, so that the general curvature of the crown is but little interrupted. In the second the rays and their divisions are rounded exteriorly, and the interbrachial spaces relatively depressed, so as to emphasize the appearance of divergence above alluded to.

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[1] *Ibid.*, 1886, p. 742.

[2] The Perisomic Plates of the Crinoids, Proc. Acad. Nat. Sci., Philadelphia, vol. 42, 1890, pp. 345-375.

There is not the slightest difficulty in distinguishing between such forms as *Lecanocrinus* on the one hand, and *Taxocrinus* and *Onychocrinus* on the other, by the above character. But there are occasional species otherwise characteristic of the first group, which are rather deeply furrowed between the rays and arms, and some of the second whose arms are habitually rather closely packed together, which we could not so readily assign to their respective groups, except for their evident connection with related genera whose characteristic species fall within them without any trouble. There are also a few forms which we are inclined to transfer from the group which they superficially resemble, because of some peculiar association of other characters which indicate a probable closer relationship elsewhere.

Now I confess myself unable to point out any satisfactory morphological basis for the difference in habitus between these two divisions, and I have much doubt as to its structural importance. Yet it is so constant and well marked in many cases, and affords such a palpable and convenient means of separation in this perplexing group, that we find it of some use in our classifications. Both forms existed in the Silurian, and continued into the Carboniferous; the first one greatly diminished and ending in the Burlington limestone, and the second continuing with increasing importance to the end of the Lower Carboniferous. The first division comprises a little group of rare genera, mostly confined to the Silurian, but with evident descendants in the Devonian and Carboniferous; they are mostly of small size. In the number of primibrachs and the absence of interbrachials they fall together nicely, and in the structure of the anal side they represent, for the most part, an earlier stage of development of the *Sagenocrinus* plan than those of the other division. The second division, with the divergent arms, embraces genera of both forms of brachial modification, and also the two leading types of anal structure. It appeared in the Silurian, and steadily increased to the close of the Kaskaskia, where it is represented by its most conspicuous example, *Onychocrinus*.

It is evident that most of the modifications above considered have influenced the line of succession from the primitive type of this group, and its separation into subordinate divisions. Each of them is doubtless a factor entering into the classification that nature has made—though of very different values—and the probability is that every natural division which has been produced is a composite, the resultant of the interaction of two or more of these tendencies to modification upon independent lines. Just how much influence each has had in fixing the line of succession we have no means of determining. It is possible to arrange the genera upon the basis of either one of the leading morphological changes I have mentioned; but whichever is selected for this purpose, we find our arrangement more or less disturbed by some of the others. For example, a fairly satisfactory arrangement could be based upon the modification of the primary brachials, which would correlate quite well with other characters, if it were not for the fact that this would throw *Sagenocrinus* and *Forbesiocrinus* into different families; whereas the connection between these genera is so evident, and the line of descent so probable, that any scheme which compels their separation is unacceptable. We cannot, of course, represent lines of descent in space of two dimensions, so that anything in the way of a diagram or table would be imperfect, even if we knew all the facts. Still less is it practicable when many of the relationships rest wholly upon conjecture.

In some groups of the crinoids family divisions are most sharply marked. No one need ever be in doubt, from inspection of the calyx alone, whether a Camerate crinoid belongs to the Rhodocrinidae, Melocrinidae, Actinocrinidae, Batocrinidae, Platycrinidae, or Hexacrinidae. This cannot be said of the Flexibilia. By reason of the fundamental difference in construction of the two groups, there is not in the latter that sharp demarcation between calyx and arms which is so characteristic of most of the Camerata. Here, on the contrary, in by far the greater number of the genera, the calyx passes into the arms by imperceptible gradation, so that in the fossil state, being usually unable to see any part of the tegmen, we cannot tell with certainty where the calyx ends and the free arms begin. The different modifications of this structure also shade into one another by various transitions, so that groups of family rank may be formed, as above stated, which differ somewhat according to the character which is taken as the basis of division.

Nevertheless, it seems possible to form a reasonable opinion as to the relative importance of the characters as the basis for large divisions:

1. The differentiation of the anal area, being completely developed in the earliest Silurian, and continuing almost to the end of its history, may be taken as marking the most primitive division of the group. It evidently dominated the lines of descent throughout, and should therefore be accorded first importance in the definition of families, all others being subordinate modifications affecting one or the other of these lines, but probably not interrupting them.

2. The presence or absence of interbrachials affords a useful basis for subordinate divisions.

3. The differentiation of the brachial system in the number of primary brachials, although evidently affording characters of much importance, is one which has impressed itself with varying force upon the two primitive lines, and not in parallel progression. It may be assumed to be a subordinate modification, marking the limitations of genera, and perhaps of sub-family divisions.

4. The difference in general form and habitus, while not explainable upon any known morphological ground, and therefore with our present knowledge apparently of less value than either of the foregoing, nevertheless furnishes a ground for division which is of some practical importance in the construction of a table, and it may therefore be given a rank in our classification perhaps higher than it at present logically deserves.

The other modifications are so palpably limited in their effect upon the history of the group that they need not be considered except in the separation of genera. I do not believe that the distal arm structure is a good character for the definition of families. It appears in parallel successions in other groups of the crinoids, from more or less equal branching to radial extensions in the form of main arm-trunks or branches bearing subordinate ramules. This is conspicuously shown among the Camerata in several of the best defined families, viz., in the Rhodocrinidae from *Rhodocrinus* to *Rhipidocrinus;* in the Melocrinidae from *Glyptocrinus* to *Melocrinus;* in the Actinocrinidae from *Actinocrinus* to *Steganocrinus;* in the Platycrinidae from *Platycrinus* to *Eucladocrinus;* and in the Hexacrinidae from *Arthracantha* to *Hexacrinus.* Yet there can be no thought of questioning the arrangement of those clearly defined families on account of such arm characters, or for contending that they represent anything more than a minor variation.

The arrangement of which I am at present in search is one for practical utility, that will facilitate the study of this group; and I am not attempting to express fully the phylogenetic relations of the various forms even as I might conceive them to be, although I have tried to recognize some of the evident lines of descent. Taking as a basis the primitive differentiation of the anal system, the Flexibilia may be divided into two groups, and the first of these may be again divided upon the infrabasal development, the interbrachial system, and the general form and habitus. This will give two main divisions, A and B; and three subdivisions under A. In this way the known genera of the group—with the exception of some transition forms whose place is difficult to assign—will fall into four family divisions, which differ from one another in various degrees, accordingly as one or the other character is given the greater importance. Each division or family contains further groupings of genera based upon some of the other characters, which might be given subordinate designations according to differing notions of their value.

This might be considered an imperfect attempt to work out the resultant of the several modifications which I have mentioned, and it necessarily encounters difficulties which can be evaded only by some arbitrary—and perhaps temporary—disposition of the disturbing elements. As to these no scheme will ever be perfectly satisfactory, and there will always be some shifting of opinion by different observers, and even by the same observer from different points of view. For instance, some of the characters cannot always be given the same order of precedence in the tables. If we had genera showing every possible combination we have discussed, it might be practicable to construct a table with some uniform order of sequence. We do not, however, find all such combinations, and it is quite conceivable that they were never all accomplished. But it is also to be confidently expected that some additional ones will yet come to light, and we can readily point out vacancies remaining to be filled by future discoveries.

The most important difference between the present and former arrangements lies in the separation of Lecanocrinidae from Ichthyocrinidae, consequent upon the discovery of the true dominating character of the latter, viz., the suppressed infrabasals. The recognition of this relation cleared up the most troublesome question that I had previously encountered in the classification of the Flexibilia.

# NEW RESEARCHES

## On the Ontogeny of some Recent Crinoids bearing upon the Phylogeny of the Flexibilia

I have long had a suspicion that in the comatulid genus formerly called *Actinometra* there might be possibilities of new information touching larval growth, for comparison with developmental phases of the ancient crinoids, more satisfactory than that obtained from *Antedon,* the only crinoid whose larval stages have been heretofore known—a genus which, as has been remarked by Agassiz [1] and myself,[2] and later by Clark,[3] is not a typical representative of the class, and hence, as Mr. Clark remarks, one of the least satisfactory for purposes of phylogenetic investigation. As long ago as 1901, in my memoir on *Uintacrinus* just cited, when discussing the possible effect upon the calyx of changes due to the movements of the rectum, I said on p. 56:

> It would be a most important thing if somebody could work out the life history of *Actinometra,* as W. B. Carpenter, Wyville Thomson, and Bury have done for *Antedon.* There are several species which seem to be sufficiently littoral in habitat to make this practicable. The " pentacrinoid " stage of *Act. meridionalis* has been seen.

And at several times since then I have made plans for such an investigation which for various reasons always fell short of execution. Recently, however, I had the extraordinary good fortune to come into possession of a brood of " pentacrinoids " of the identical species above mentioned taken on the coast of Yucatan. They form a series ranging from the sessile pre-brachial stage to that in which the orals are resorbed, all permanent elements of the skeleton fully established, and the stem discarded for a free existence. Upon examining them under a microscope it was clear that we had in these young comatulids the evidence of a course of development in oral, interradial, and anal structures considerably different from that seen in *Antedon,* and which is analogous in an extraordinary degree to the condition and progressive modification of these structures in the fossil Flexibilia. To accurately determine the different stages exhibited by these specimens, and make drawings for such as might be desired for illustration, involved a laborious investigation with technique in microscopy which I do not possess. But this has been accomplished by my assistant, Dr. Herrick E. Wilson, with patience and skill to which the three plates of figures, A, B and C, bear ample testimony, and for which I wish to here record my acknowledgments. I have thought it more satisfactory to reserve the description of this new material, which has a direct bearing upon several of the elements already discussed, for a separate chapter in which its relations to the former matters may also be explained.

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[1] *Calamocrinus,* Mem. Mus. Comp. Zoology, Harvard, vol. 17, no. 2, 1892, p. 52.

[2] *Uintacrinus, ibid.,* vol. 25, no. 1, 1901, p. 38.

[3] Monograph of the Existing Crinoids, 1915, p. 331.

There are in all 200 specimens of the larvae, which were found clinging to the cirri of several young individuals of *Comactinia* (*Actinometra*) *meridionalis,* a widely distributed littoral species. They show almost every stage, from that of a nearly closed cup of basals and orals with faint incipient radials and a long, tapering stem, through development of anal, radial, and interradial structures, arms, pinnules and cirri, to those of diminution and ultimate resorption of orals and interradials and loss of stem. A series of specimens has been selected for figuring to represent the various phases of this development, to which I have added for comparison an adult specimen from another locality (Plates B and C). The minute "pentacrinoids," from .31 to 1.85 mm. in diameter of calyx, were attached to the cirri of the host by the usual flat, encrusting plate (Pls. B, fig. 6; C, fig. 7), similar to that of the fossil *Calpiocrinus* (Pl. VII, fig. 1*a*) and *Taxocrinus* (Pl. L, fig. 1). Some of them have already been figured by Mr. Clark in his Monograph of the Existing Crinoids—see on p. 317, figures 408 and 412; plate 4, figure 548.

The outstanding difference in the development of this type from that of *Antedon* lies in the position, size, and much greater sweep of migration of the radianal, and in the prominence of the anal tube—both evidencing the great importance of the movements of the intestine in producing changes in the form and composition of the calyx, as indicated in my paper of 1906, already quoted. And in these characters the analogy between the larval stages of this living crinoid and the successive phylogenetic modifications of the group Flexibilia is most remarkable. It will be remembered that in W. B. Carpenter's account of the growth of the calyx in *Antedon rosaceus* the so-called anal plate was first observed to appear "between two of the radials, and at the same level with them." That is the position shown in Sir Wyville Thomson's figure[1] of its first appearance as observed by him; and in none of the researches upon species of that genus has this plate been noted as beginning in any different position. In the present material, however, we shall see that it appears in a far more primitive position.

Our series of *Comactinia* larvae begins (Pl. B, fig. 1) with a calyx composed almost exclusively of basals and orals, the latter closed and standing quite erect; and a stem with ossicles lengthening distally, on which cirri have not begun to appear. The plates at this stage consist as usual of a thin calcareous reticulation formed by spicules imbedded in undifferentiated sarcode; later this reticulation progressively consolidates, thickens, and becomes a less and less porous skeletal substance. Very small patches of stereom, which are the beginnings of radials consisting of a few spicules, have appeared in the rhombic spaces between the corners of basals and orals; but in one of these spaces the radial is wanting, and in its place there is a somewhat larger plate similar in composition to the others, which is attached[1] to the anal end of the intestine, now plainly visible at the outer surface of the calyx. This plate is the radianal, which now lies in the position which the radials occupy in the other areas, being at the foot of the area to be occupied by the right posterior ray. This position, therefore, is essentially that which is held by the radianal in the earliest genera of the Flexibilia, *Protaxocrinus, Ichthyocrinus,* etc., called the primitive position; and it is also the position indicated for the primitive radianal in my hypothetical figure of 1906 before mentioned (Pl. A, fig. 7). The anus is also in the position which it permanently occupied in some Paleozoic genera of the Inadunata, viz., the zone of the basi-radial sutures. In this first specimen the calcareous reticulation is so thin and translucent that by transmitted light the complete alimentary system is plainly visible, consisting of the oesophagus, stomach, and dextrally coiled intestine, as shown in the figure, which will be more fully described presently; the closure of the orals has compressed the mouth of the oesophagus so that its margin appears crenate or folded.

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[1] Philosophical Transactions Roy. Soc. London, 1865, p. 529, pl. 27, fig. 1.

There are two specimens in which this stage is distinctly shown, and it may for convenience be called the "*Actinometra* stage." The second specimen is shown in Plate B, figure *2a;* in this the orals, while of the same relative size, are slightly parted and the oral tentacles project between their summits but have not yet branched; as in the first specimen the radial of the right posterior ray has not appeared, but its place is occupied by the radianal attached to the gut. Although the projecting tentacles make this specimen appear the more advanced, the radianal is smaller than in the other one; the difference is due to the slight opening of the orals, which stretches the mouth so that its upper edge is without wrinkles (fig. *2b*).

In the next stage represented (Pl. B, fig. 3) the right posterior radial has appeared, and beneath it to the left is the rapidly enlarging radianal attached to the gut, which is still visible through the thin reticulate stereom of the calyx wall just below the anal opening. The disparity in size between the two plates is important as tending to confirm the antecedent appearance of the radianal in the first stage, and its status as an independent element. The aperture of the gut is here very distinct, and the intimate attachment of the plate to the gut just below the opening is evident.

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[1] While there is probably no direct attachment of the radianal to the hind gut, except that it lies close to the anus in the sarcode that is attached to the gut, the word "attached" is used here and throughout this discussion to express the intimate degree of association between the radianal and the hind gut, which in behavior is more that of attachment than of association.

In figure 4 the radials have notably increased in size, and above them at the base of the tentacles may be seen two small disconnected plates which are the beginnings of the first and second primibrachs; the radianal is enlarged to a smaller degree, and it lies to the left of the radial which now begins to curve around it toward the middle of the posterior basal, as in *Lecanocrinus* and *Gnorimocrinus;* the gut has become concealed behind the radianal except at the opening which is visible at the apex of that plate. The radianal is now in the stage of its first appearance in *Antedon* before mentioned, as described by Carpenter, Thomson, Mortensen and others, and this may appropriately be called the "*Antedon* stage."

The next stage is represented by figures 5*a* and 5*b,* posterior and anterior views. The radials have enlarged until they almost come into lateral contact except posteriorly; the two primibrachs have thickened and become connected with the radial and with each other, the second one being an axillary covering the base of the tentacles, now three in number; basals and orals have become relatively smaller owing to the superior growth of the radials; and the radianal is about on a level with the radial to the right of it, indenting its left side and still touching the sloping shoulders of the posterior basal, comparable to its position in *Forbesiocrinus* and *Taxocrinus.* In the triangular spaces between the radials and orals small plates appear which are readily recognized as the interradials, formed in the same manner as other calyx plates; their position is such that if they should develop downward to a connection with the basals, there would be produced an interradial system like that of the Rhodocrinidae, and if upward, as they actually do, like that of the Taxocrinidae. The orals now exhibit rather distinct pores distally which may be analogous to those seen in *Holopus* (Pl. A, fig. 8), and in the posterior oral alone of *Onychocrinus* and other Flexibilia.

A specimen at about the next stage with complete stem as it appears attached to a cirrus is shown by figure 6 of Plate B. In this and succeeding stages shown by figures 7, 8*a,* 9, 10, of Plate B, and 1*a, b,* of Plate C, the radials increase in size until they greatly exceed the basals, which now form a low and nearly horizontal basin; the interradials have been pushed upward by the radials meeting below them, and have increased in number from 1 to 5 or 6 in the regular areas and bordering the radianal as well, where they pass over into the plates of the heavily plated integument which is extended upward into a large conical protuberance, now definitely constituting the anal tube, analogous in form and position to that of the Taxocrinidae; the gut has continued to extend itself upward, until its opening is now at the apex of the conical projection rising far above the orals, which by the multiplication of interbrachial plates are now being more and more separated from the dorsal cup and relatively reduced in size; the radials have met and form a closed ring;

solidly calcified arms have replaced the tentacles, and short stumps of cirri have appeared upon the proximal columnal. Thus all the various elements of the crinoid skeleton are now represented, with the single exception of the pinnules. Figure 8*b* is a lateral view of the original of figure 8*a*, showing the extreme distortion of the calyx caused by the bulging of the gut.

The stage represented by figures 1*a*, *b*, of Plate C is of special interest as showing the condition reached by the oral plates. These now form a low pyramid around the mouth, reduced by relatively one-third from their former size, and disconnected not only from the basals by the large radials which have closed into a complete ring, but from the radials themselves by the extension of a band of interradial plates which tend gradually to pass over into the perisome. It is substantially the stage represented by the tegmen of *Holopus* (Pl. A, fig. 8), of the young *Thaumatocrinus* (fig. 9*b*), and of the adult *Ptilocrinus* (Pl. LXXV, fig. 1*c*).

From this time on the resorption of the orals rapidly proceeds, and concurrently with it is seen a growing differentiation between the interradials and the ventral integument, which is more and more transformed into undifferentiated perisome. The resorptive process also involves the radianal, which has now been left far behind by the protruding anal tube, and is actually as well as relatively diminished in size; the same relative decrease is true of all the dorsal elements of the calyx, which have become nearly flat and collectively serve merely as a shallow saucer for the support of the visceral mass.

These conditions are shown by figures 2*a*, *b* and 3*a*, *b*, of Plate C, in which the pentacrinoid is almost ready to cast off its stem, prehensile cirri having now developed to a length of 7 or 8 segments, with strong terminal claws suitable for fixation; pinnules of considerable size have also made their appearance; the ventral perisome, still further expanded, is now studded with a multitude of indefinite plates, from which the interradials are well differentiated though reduced in number and evidently in process of resorption; ambulacral grooves have appeared, traversing the perisome from the arms to the mouth, and passing in between the orals which are now reduced to very small triangular plates (Pl. C, fig. 3*b*), the posterior plate in this view being hidden by the anal tube which has become still more conspicuous and rises high above the general level of the disk. The radianal is now entirely above the radial circlet and no longer forms a part of the dorsal cup; the perisome at this stage is covered with a sort of velvety coating in which the numerous small plates are difficult to distinguish, and it is evidently on the verge of transformation into the granular skin of the adult stage from which all plates ventrally situated, including interradials and radianal, have been completely resorbed. The stage thus represented by figures 3*a*, *b* of Plate C is identical with that of the Paleozoic *Onychocrinus*, but lacking the greatly enlarged and madreporic posterior oral, which is a feature not yet discovered in any Recent crinoid. With that exception the tegmen of this comatulid larva might almost be taken to be of the same genus as those figured on Plates LXVII and LXVIII.

The radianal, after being left far behind by the rectum when carried upward with the anal tube, is resorbed along with the interradial plates, from which in the later stages it scarcely differs, as is shown by figure 4 of Plate C, a dorsal view of a specimen which has cast off the stem (the cirri beyond their stumps being omitted in the drawing).

It will be observed in this figure that the basals are no longer visible, having been fused into the "rosette"; the orals in the stage represented by this specimen have also vanished. Thus it results that the two rings of plates which at the beginning of the series composed practically the entire calyx have now completely disappeared; and instead of the globose cup which enclosed the viscera in the youngest larval stage, there remains only a flat basin, serving as a mere support for the relatively greatly enlarged visceral mass.

To show the final outcome of the changes above described, I have figured the tegmen of an adult specimen of the same species (Pl. C, fig. 5). All that is left of the several ventral structures is the granular skin, subcentral anal tube somewhat flattened by shrinking, and the exocyclic mouth with the asymmetric ambulacra, both permanently displaced by the pressure of the rectum.

The origin and development of the radianal as shown in the *Comactinia* series is paralleled in a series of *Promachocrinus kerguelensis,* loaned me by Mr. Clark out of a set of larval forms studied by him from the collection made by the German South Polar Expedition near Gaussberg, in the Antarctic, and now in his hands for investigation. I have figured a few of the specimens, on account of the decisive way in which they reinforce the foregoing observations and conclusions (Pl. A, figs. 10-14). The series begins with the pre-brachial stage like our *Comactinia* (figs. 1 and 2), in which the radials have just begun to form as small dots, but in this case all the radials have appeared, that of the right posterior ray being smaller than the others and the radianal much larger, having already passed to the left of it. From the great difference in size of these incipient plates it seems probable that the radianal, as already suggested by Mr. Clark, actually developed before any of the radials were formed. In the several stages which follow, the radianal does not increase to the relative size which it attains in *Comactinia;* but it runs a similar course until it is lifted out from the ring of radials by the growth of the anal tube, and the interradial spaces have become occupied by the interradial radials characteristic of this genus. It must be remembered when examining the figures here given that they do not represent the true relative sizes of the specimens; for convenience they are drawn of about the same general dimensions, but for the actual relation between them as to size attention must be given to their accompanying signs of enlargement.

The anatomical processes by which the foregoing changes in the larvae of *Comactinia* (*Actinometra*) are accomplished, as contrasted with those in *Antedon,* are as follows:

Observation by transmitted light of two specimens in the early prebrachial stage (Pl. B, figs. 1, 2*b*), confirmed by dissection of another, shows that the alimentary canal consists of a mouth, surrounded by a narrow lip from which the oral tentacles spring; a short, broad, funnel-shaped oesophagus; a horizontal portion distended transversely resembling the human stomach, into the larger end of which the oesophagus opens; and a slender intestine ending blindly which originates from the smaller left end of the stomach, makes a half twist and coils dextrally around it. This simple alimentary system is loosely suspended in the coelom by threads and lamellae of connective tissue, and is in contact with the inner wall of the cup only at the mouth and the posterior end. The intestine in its development has coiled dextrally around the stomach, then turned obliquely upward towards the posterior interray; the upward turning having started near the middle of the anterior border of the right-posterior basal, and ending in this stage with the formation of the anus slightly to the right of the posterior interradial plane, on a level with the distal margins of the incipient radials. The upward bend of the intestine, which appears in the posterior interray of *Antedon* shortly after the "*Antedon* stage" is reached, in this form does not come to lie in the posterior interradius until a very much later stage of development. Dissection at the stage of figure 9 shows the upward turn still to the right of the posterior interray. As the cup expands laterally and vertically the intestine also expands, but growing more rapidly than the calyx soon fills the body cavity. The radianal, formed previous to and just below the anus, is parallel to the intestine at that point, and evidently very firmly attached to it,[1] as shown by its subsequent migration. The upward growth of the cup and the concomitant dextral growth of the intestine carry the radianal and the anus upward and into the plane of the posterior interradius; which by reason of the retirement of the oral distalward is the path of least resistance. When the portion of the intestine to which the radianal is attached comes to lie in a vertical position along the plane of the posterior interray the radianal is completely withdrawn from the radial circlet, and rests equally upon the truncated, disto-lateral margins of the posterior radials (Pl. B, fig. 10). Its migration follows the upward and dextral growth of the intestine, which does not bend sharply upward along the posterior interray; the radianal for a considerable time holds closely to the right-posterior radial, thus causing inhibition of its lateral growth and its peculiar asymmetrical development (Pl. B, fig. 8*a*). The path of this migration is indicated by the dotted line in figure 6 of Plate C, and the course of the plate is also that of the anal end of the intestine to which it is attached. If on the figure of the primitive *Protaxocrinus* (Pl. XLVI, fig. 8*b*) a line is traced from the radianal to the end of the tube, it will be found to follow the same course.

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[1] See foot-note, p. 81.

The course of the radianal in the successive stages shown by this series of comatulid larvae is closely paralleled by its position at corresponding stages in the phylogeny of the Paleozoic crinoids, especially the order Flexibilia. Figures 1 and 2, Plate B, with the radianal at the base of the potential right posterior ray, are analogous to the stage of the Ordovician and Silurian *Protaxocrinus, Ichthyocrinus, Clidochirus,* etc.; figures 3 and 4, obliquely below and to the left of the radial, to that of the Silurian *Lecanocrinus* and *Gnorimocrinus;* figure 5, in the notch between the right sloping face of the posterior basal and the radial, to that of the Carboniferous *Forbesiocrinus* and *Taxocrinus;* figure 7, midway between the two posterior rays and symmetrically truncating the basal, to that of the so-called anal *x* in the Devonian and Carboniferous *Dactylocrinus* and *Mespilocrinus;* while specimens in the stage of figure 5, Plate C, with all anal structures eliminated from the dorsal cup, represent that of the Carboniferous *Nipterocrinus* and *Wachsmuthicrinus.* And throughout the series of larval changes there is to be observed the same tendency of the anal structures to bend to the right which, as I have before pointed out, prevails among the genera of the Flexibilia. Even in the tegmen of the adult there is not perfect symmetry.

I have called the migrating plate the "radianal," following the course of Mr. Clark already quoted,[1] which was the result of conference between us, because it seems to be perfectly homologous both in position and function with the plate of that name in the Flexibilia and many of the dicyclic Inadunata of the Paleozoic crinoids, at least up to the stage in which it assumes the function of the symmetrically located first plate of the median anal series. We know that in our comatulid larvae this plate is not replaced or changed in any respect except by its migration and ultimate resorption, because it is fixed to the gut, and is lifted with it by the upward growth of the tegmen from its point of origin to its latest position. But in the phylogeny of the fossil forms the permanent fixation of interradial plates in some of them introduced another element, which would have to be accounted for in the posterior interradius as well as in the regular areas, and an intermingling of characters with the radianal may have resulted.

It is thus clearly demonstrated that these great morphological changes are due mainly to the growth of the gut and its mode of discharge, phases of which when fixed paleontologically become the strongest characters for the delimitation of genera. That in some of the fossil stages the radianal plate became fixed in its primitive or early position, and did not follow the distal end of the gut in its growth, might on first thought seem a singular fact, but it is no more so than the fact that the two structures part company when the radianal is left behind in the larva.

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[1] Jour. Washington Acad. Sci., 1912, p. 310, 311; Monograph of the Existing Crinoids, 1915, p. 332.

Recalling now the descriptions of the origin of the radianal, or the so-called anal plate, in *Antedon* and *Comactinia* as given in the foregoing pages, which I have called the "*Antedon* stage" and the "*Actinometra* stage," respectively, it will be observed that we have in these two types stages of anal development comparable to those of important contrasting fossil groups both in the Flexibilia and the Inadunata:—the *Antedon* stage to that of the median anal series of the Cyathocrinidae and some of the Silurian and Carboniferous Flexibilia, and the *Actinometra* stage to that of the more primitive *Dendrocrinus, Protaxocrinus* and *Lecanocrinus* groups. Apparently the *Antedon* stage is characteristic of a considerable group among the Recent crinoids, since we have proof of it in at least two widely different species. The *Actinometra* stage is as yet strictly known in only one species, the development of *Promachocrinus* (which is classed among the Antedonidae) being a little different in detail from that of the others.

The relations of the medially situated anal plate in *Antedon* are by no means clear, and there is strong reason for doubting if it can be placed in the same category as the migrating plate in *Comactinia*. Its first appearance is in an interradial position, where by growth from above it truncates the posterior basal distally. Its position and mode of growth are not (except for its evident connection with the movement of the gut) essentially different from those of the interradials in *Comactinia* and *Promachocrinus,* or from those of the interradials in fossil forms like the Reteocrinidae or Rhodocrinidae, or some exceptional Flexibilia, in which they extend downward to a connection with the basals. The radianal of *Comactinia,* on the other hand, is of a strictly radial origin, and by shifting toward the left and upward it truncates the posterior basal first laterally and afterward distally. Therefore we may have in these two existing types of anal structures representatives of the two principal types in the fossil forms, viz., that with median plates only, and that with asymmetric radianal.

Generalizations upon these conditions, or attempts to point out definite homologies, must be made with much reserve. Nevertheless, according to the foregoing facts, we have in the ontogeny of this living crinoid an unusually close recapitulation of the phylogenetic history of some of the Paleozoic groups of the class.

## THE PHYLOGENETIC RELATIONS OF THE FLEXIBILIA

The order Flexibilia is now considered to be an offshoot from the dicyclic Inadunata, through modifications resulting in an open mouth and the loose incorporation of brachials in the calyx. This opinion was expressed by Bather[1] in 1900, and by myself[2] in 1911. Up to the latter date no definite line of connection between the two orders had been pointed out, but in the paper last cited I was able to furnish the evidence of such connection through the non-pinnulate Dendrocrinidae—the exact nature of whose tegmen has not yet been discovered—and at so early a period as to indicate close proximity to the stage of divergence from a common ancestor.

The earliest known representatives of the Flexibilia are the two species from the lower Trenton rocks of Canada described by Billings[3] under *Lecanocrinus,* but now falling under the recently established genus *Protaxocrinus*—*P. elegans* and *P. laevis.* The specimens figured by Billings did not disclose the essential structures of these forms, and their position remained for a long time in doubt. In my paper of 1906, p. 502, I expressed the belief that they had the *Taxocrinus* anal side; this was confirmed by later discoveries proving that they belong not only to that genus, but to the most primitive form of the Taxocrinidae, viz., with a radianal in primitive position directly under the right-posterior radial. This structure of the Ordovician species was demonstrated in the above cited paper on A Trenton Echinoderm Fauna, p. 11, with figures, and it is now more fully described with additional illustrations (Pl. XLV, figs. 1 to 7; see also figures of other species on the same plate).

*Protaxocrinus,* as will be observed from these figures, is a form having, along with its primitive radianal, a strong anal tube rising quite high between the arms, composed of a vertical row of large plates bordered by perisome and connected in the lower part more closely with the right posterior ray than with the left; and having also in the interradial areas usually one definite plate followed by perisome. It has also variable arcuate sutures often much effaced by wear; and two primibrachs. In the paper last cited I also gave a full account of some species of the Dendrocrinoid genus *Cupulocrinus,* of which I had obtained some unusually fine material (*op. cit.,* 1911, pp. 28-36; pl. 1, figs. 8 to 12; and pl. 3, figs. 1 to 9; and text-fig. 2, on p. 29). Two of these species occur at the same locality and in the same lower Trenton formation as those of *Protaxocrinus* above mentioned; and a third, before undescribed, which I now call *Cupulocrinus minimus,* is a recurrent form in the Richmond formation of the Cincinnati area. For convenience, I have reproduced several of the most significant figures on Plate LXXV, figures 2 to 6; but in this connection the entire series figured in the Canadian memoir should be consulted.

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[1] Lankester's Treatise on Zoology, pt. 3, pp. 140, 187.

[2] A Trenton Echinoderm Fauna, Mem. Geol. Surv. Canada, No. 15P, p. 35.

[3] Canadian Organic Remains, Decade 4, 1859, p. 47, pl. 4, figs. 3*a*, 4*a*, *b*.

The species of *Cupulocrinus* thus before us have a primitive radianal; an elongated anal tube supported by a prominent median series of strong plates bordered by perisome, inclining to the right and in closer connection with the right posterior ray than with the left; the interradial areas occupied by numerous small, irregular plates, with sometimes a single larger one in the axil; arcuate sutures variably present and sometimes extremely prominent. If to these characters were added that of three unequal infrabasals (readily produced by fusion of two pairs out of the five present here), and of an open mouth, I would defy any paleontologist to show wherein the specimens of these species differ generically from those of *Protaxocrinus* illustrated on Plate XLV. Even the stem, with its conical taper in one species and its alternating columnals in the others, would go perfectly well with various Flexibilia. In the arcuate sutures we have one of the strongest Flexible characters, and any collector familiar with the crinoids of that order finding a fragment of arms or brachials of a specimen like that of Plate LXXV, figures *2a, b,* would say at once that it belonged to the Flexibilia.

As to the tegmen, we do not know its exact character, except that it is composed of pliant perisome, a direct extension of that developed in the interradial areas. Neither orals, mouth or ambulacra can be seen in any of the specimens. The anal tube is directly connected with the perisome for its full length (Pl. LXXV, figs. 4, *6a, b*), and there is no doubt that the opening is in a fold or extension of the pliant tegmen, just as I have shown it in *Onychocrinus* and *Taxocrinus.* The whole ventral structure is absolutely different from that of most other Inadunata in which it is known, notably in the Poteriocrinidae and Cyathocrinidae; and in the way it differs from them it approaches that of the Flexibilia.

The number and distribution of primibrachs are different from those of the Flexibilia generally; but although regularly unequal in the different rays of one species, and irregular in those of another, some phases of these variations are the same that have become fixed characters in different genera of the later Flexibilia, as the three IBr of *Taxocrinus,* and the three or four in *Onychocrinus.* The inequality and irregularity in number of primibrachs is a character unknown among the Flexibilia except as sporadic variations, and upon this character, if taken alone, we should be inclined to range these forms under the Inadunata. There is clearly an intermingling of the characters of the two orders, and it is evident that in *Cupulocrinus* we have to deal with a transition form whose exact status is difficult to decide from what can be seen in the fossil. Some of the other transitions which might occur are not difficult to interpret; for example, the fusion of two pairs of the primitive five infrabasals, which has actually occurred within the limits of a single Inadunate family between *Cyathocrinus* and *Gissocrinus.* The fact that both of the Trenton genera in question are in the same primitive stage in the development of the radianal, a character which is now shown to be of the very highest importance in the phylogeny of the crinoids, adds greatly to the significance of their close approach in other characters. It should be added that the two species of *Cupulocrinus* are extremely abundant and range throughout the principal Canadian localities and southward to Kentucky, while *Protaxocrinus* is one of the rarest fossils in these rocks.

Having, therefore, two contemporaneous genera in the earlier Ordovician, existing at the same locality and horizon, and being in the same morphological condition in regard to the one strongest and several of the minor characters; the one flourishing in profusion and the other extremely rare; we have the very conditions under which we might expect to find evidence of evolutionary changes marking the divergence of two higher groups which are admittedly of a common origin. The divergence in these two forms is of so simple a nature, and by such close steps, that we need not look so very far back in the geological scale for a probable common ancestor; and we may yet hope to find it in the Ordovician.

A somewhat analogous convergence of some characters is to be noted between the forms just discussed and the Camerate family Reteocrinidae, as exemplified by such species as *Reteocrinus o'neali* (Pl. LXXV, figs. 7, 8). In the pliant tegmen passing down into the interradial areas, and the strong vertical series of anal plates leading to an opening through the perisome, there is certainly a marked similarity. But except for its pliability there are in these forms none of the characteristics of the Flexible tegmen, such as the exposed mouth and ambulacra. I have a hundred or more specimens of *R. nealli* exposing the tegmen in a similar condition to that shown in these figures, and I have studied them with great care to find a trace, a survival, or a premonition of mouth or ambulacra, but without success. And it seems to me that these organs must be regarded as definitely in the subtegminal stage of the Camerata, but with transitional phases toward or from the Flexibilia. This form belongs to a later period—Silurian—but another species of *Reteocrinus* is of the same age as the principal species of *Protaxocrinus* and *Cupulocrinus* above discussed; so that all three types may have coincided in time and place as representatives of the transitional tendencies out of which the three greater divisions of the crinoids were evolved.

Another clearly transitional form, also from the same older Ordovician formation, is the genus *Cleiocrinus.* Its position seems to lie between the Flexibilia and the Camerata on the one hand, and between these and the cystids on the other. In regard to the calyx, the general habitus of the specimens, the articulate structure and flexible walls, point strongly toward the Flexibilia of the type having a solid posterior interradius and no anal tube; yet the presence of pinnules, and of five infrabasals instead of three, differentiate it from the known Flexibilia. On the other hand the brachial structure, the form and arrangement of arms and pinnules, with ridges following the radial lines and running into the arms, are essentially the characters of *Glyptocrinus* or *Reteocrinus.* To the full description of this genus, and explanation of its anomalous basal structure in which it differs from all other crinoids, as given in my memoir of 1905,[1] I added in my Canadian memoir of 1911 (*op. cit.,* p. 43, pl. 5, figs. 7-11) evidence proving that the mode of union of the calyx plates is clearly that of the cystids, with the calycine pores and rhombs of that group in abundance. The form is too symmetrically organized to remain with the cystids, and it will not fit into any of the recognized orders of the crinoids. Hence it must be treated simply as an intermediate form, evolved late from the cystids, but whose crinoidal tendencies had not yet settled into a definite line of development.

Thus it seems that at this very early stage in the geological scale we have several forms exhibiting variously intermingled characters of the larger divisions of the crinoids, with some of the essential cystid structure more or less impressed upon one of them; and that these represent relatively recent departures from the common ancestral type, tending in different degrees toward the lines of evolution which produced the several orders of the crinoids. In *Protaxocrinus* the Flexible characters were already well established; in *Cupulocrinus* and *Reteocrinus* the tendency was toward the Inadunata and Camerata respectively, while still complicated by other characters; while in *Cleiocrinus* the strong survival of cystid characters prevented the establishment of a distinct evolutionary line in either of the crinoidal orders.

The Flexibilia, like the Camerata, were limited strictly to the Paleozoic; and if they left survivals these were so overshadowed by the great changes which occurred in Mesozoic and Recent times, that they must be considered as wholly subordinate, and not of sufficient weight to maintain this order as a zoological concept. The calyx of *Uintacrinus,* with its profuse interbrachials and flexible walls, seems at first glance remarkably similar to that of some forms of the Flexibilia. But *Uintacrinus* is essentially a comatulid with remarkable protean and convergent characters, as I suggested in 1901,[2] and as has since been fully demonstrated by Clark.[3] The resemblance is superficial rather than morphological, the very thin plates of *Uintacrinus* being totally opposed to the brick-like structure of the Flexibilia.

The exposed mouth and ambulacra of the Flexibilia constitute, of course, their most striking character which has come down to present time and which prevails universally among the Recent crinoids. Upon this ground it was formerly held by myself as well as others, and perhaps may still be held by some, that the comatulids and some of the Recent groups should be considered as a pinnulate division of the Flexibilia. My reasons for no longer adhering to this view have been stated in the revised edition of the Zittel-Eastman Paleontology, 1913, p. 227, and will be further discussed in the chapter on Classification.

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[1] *Cleiocrinus,* Mem. Mus. Comp. Zoology, Harvard, vol. 25, no. 2, pp. 93-114.

[2] *Uintacrinus,* Mem. Mus. Comp. Zoology, Harvard, vol. 25, no. 1, pp. 55 *et seq.*

[3] The Systematic Position of the Crinoid Genus *Marsupites,* Proc. U. S. National Museum, vol. 40, 1911, pp. 649-654.

Dr. G. Steinmann[1] in a general discussion of evolutionary principles has expressed a very positive opinion that the Jurassic Apiocrinidae are descended from the Paleozoic Flexibilia, contending that it is even possible to derive some Apiocrinidae from particular species of Flexibilia. He undertakes to trace the connection through the genus *Guettardicrinus* and *Forbesiocrinus greenei* M. and G.[2] from the Lower Carboniferous, and for the latter proposes a new genus, *Proguettardicrinus*. This is done purely on the ground of superficial resemblance and minor characters such as the number of brachials, while overlooking the broader characters such as bilateral symmetry produced by anal structures, regularly arranged interradials, loose sutures uniting the calyx plates of this and a closely related species, which decisively establish the position of this form under *Forbesiocrinus*. Some of these characters were not clearly shown by the original figure and description, but they may all be seen in full detail upon Plates XXX and XXXI of this work.

Steinmann admits that with the nonexistence of pinnules in the Flexibilia established, the chasm between the Flexibilia and the Apiocrinidae cannot be bridged; but he avoids this difficulty by assuming that in the older forms the pinnules were soft structures and therefore not preserved, while later under different physical conditions they became solidified by lime deposit. This is pure hypothetical invention, without proof or probability, but directly contrary to the fact that in the two other Paleozoic groups, existing under the same conditions and found in the same formations as the Flexibilia, calcareous pinnules are profusely developed. There are unquestionably strong points of similarity between the Apiocrinidae and some Paleozoic Flexibilia, to which perhaps more than anything else was due the opinion of Wachsmuth and myself connecting that family, as Bather now does, with this order under the Grade Flexibilia Pinnata. According to my present views, the presence in the Apiocrinidae of pinnules and of a terminal stem plate, the irregular interradials when present, the absence of a flexible calyx structure, and the admitted impossibility of tracing any line of connection with the Paleozoic Flexibilia, combine to furnish sufficient grounds for ranking them under the Articulata as now defined.

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[1] Die geologischen Grundlagen der Abstammungslehre, 1908, p. 152.

[2] Illinois St. Mus. Nat. Hist., Bull. 9, 1896, p. 57, pl. 4, figs. 1, 2.

## DISTRIBUTION OF THE FLEXIBILIA

Excluding synonyms, the number of species of the true Flexibilia recognized in this work as sufficiently known for definition is 176, belonging to 31 genera. In addition to these there are species of 6 genera which have been mentioned in connection with this order, none of which belong to it, but two of which may doubtfully represent transitional forms of some stage. These are: *Cleiocrinus, Caleidocrinus, Edriocrinus, Rhopalocrinus, Cydonocrinus* and *Sycocrinus.* Counting only the true Flexibilia, their occurrence may be graphically shown by the following tables:

### I. *Biologic*

**Number of species**

| | |
|---|---|
| Lecanocrinidae | 54 |
| Sagenocrinidae | 20 |
| Ichthyocrinidae | 40 |
| Taxocrinidae | 62 |
| Total | 176 |

### II. *Geologic*

**Number of species by families**

| | Lecano-crinidae | Sageno-crinidae | Ichthyo-crinidae | Taxo-crinidae | Totals |
|---|---|---|---|---|---|
| Carboniferous | 9 | 10 | 18 | 32 | 69 |
| Devonian | 5 | 0 | 10 | 19 | 34 |
| Silurian | 40 | 10 | 12 | 9 | 71 |
| Ordovician | .. | .. | .. | 2 | 2 |
| Totals | 54 | 20 | 40 | 62 | 176 |

## III. *Geologic* and *Geographic*

**By genera**

| | Ordovician | Silurian | Devonian | Carboniferous | America | Europe | No. of Genera |
|---|---|---|---|---|---|---|---|
| TAXOCRINIDAE | | | | | | | |
| *Onychocrinus* | .. | .. | .. | × | × | × | .. |
| *Parichthyocrinus* | .. | .. | .. | × | × | .. | .. |
| *Taxocrinus* | .. | .. | × | × | × | × | .. |
| *Eutaxocrinus* | .. | .. | × | × | × | × | .. |
| *Gnorimocrinus* | .. | × | .. | .. | × | × | .. |
| *Protaxocrinus* | × | × | × | .. | × | × | 6 |
| ICHTHYOCRINIDAE | | | | | | | |
| *Amphicrinus* | .. | .. | .. | × | × | × | .. |
| *Synerocrinus* | .. | .. | .. | × | .. | × | .. |
| *Wachsmuthicrinus* | .. | .. | .. | × | × | × | .. |
| *Euryocrinus* | .. | .. | × | × | × | × | .. |
| *Dactylocrinus* | .. | .. | × | × | × | × | .. |
| *Metichthyocrinus* | .. | .. | .. | × | × | .. | .. |
| *Synaptocrinus* | .. | .. | × | .. | × | .. | .. |
| *Cleistocrinus* | .. | × | .. | .. | .. | × | .. |
| *Clidochirus* | .. | × | × | .. | × | × | .. |
| *Ichthyocrinus* | .. | × | × | .. | × | × | 10 |
| SAGENOCRINIDAE | | | | | | | |
| *Forbesiocrinus* | .. | .. | .. | × | × | × | .. |
| *Lithocrinus* | .. | × | .. | .. | .. | × | .. |
| *Sagenocrinus* | .. | × | .. | .. | × | × | .. |
| *Meristocrinus* | .. | × | .. | .. | .. | × | .. |
| *Temnocrinus* | .. | × | .. | .. | .. | × | 5 |
| LECANOCRINIDAE | | | | | | | |
| *Mespilocrinus* | .. | .. | .. | × | × | × | .. |
| *Nipterocrinus* | .. | .. | .. | × | × | .. | .. |
| *Lecanocrinus* | .. | × | × | .. | × | × | .. |
| *Pycnosaccus* | .. | × | .. | .. | × | × | .. |
| *Cholocrinus* | .. | × | .. | .. | .. | × | .. |
| *Hormocrinus* | .. | × | .. | .. | × | × | .. |
| *Asaphocrinus* | .. | × | .. | .. | × | .. | .. |
| *Calpiocrinus* | .. | × | .. | .. | .. | × | .. |
| *Homalocrinus* | .. | × | .. | .. | .. | × | .. |
| *Anisocrinus* | .. | × | .. | .. | × | × | 10 |
| | 1 | 17 | 9 | 13 | 23 | 26 | 31 |
| | 40 | | | | 49 | | |
| Less duplications | 9 | | | | 18 | | |
| Total genera | 31 | | | | 31 | | |

Of the 176 species, 109 are American and 67 European.

It must always be remembered, in considering statistics of this kind, that the numbers represent not the totals of the species as they actually existed in the different epochs and areas, but only of the species which were preserved and are represented in our collections. The infinitesimally small proportion which the fossils obtained bear to the faunas which existed may be appreciated when we reflect that of the life periods preceding the Ordovician, which some geologists consider to have been longer than all those which followed it combined, we have no representatives whatever except a few cystids; that vast accumulations of fossiliferous strata have been obliterated by erosion during periods of elevation of the sea bottom; that the strata covering three-fifths of the earth are submerged beneath the oceans; that upon the land by far the greater part of the fossiliferous rocks are buried under those of succeeding formations, or under soil, ice, snow, or sand; that large areas are still unexplored; and that out of the strata which are accessible to us, all the fossils which are obtained by our collectors represent only the partial product of not more than a few, or a few hundred, acres. These facts are emphasized in greater detail in Wachsmuth and Springer's monograph on the Camerata, pp. 167-169. Therefore all generalizations based upon distribution must be made with this qualification.

Considering the known occurrences to represent in a remotely general way an average of the succession of crinoidal life, we may note some facts indicated by the above tables:

The Flexibilia are very feebly represented in the Ordovician, from which only two species of a single genus are as yet known, and of these specimens are extremely rare. This is in marked contrast to the prevalence of crinoids in the other orders, both Camerata and Inadunata being abundant and widely distributed. There was a rapid increase in the Silurian to 71 species, chiefly of the Niagaran or Wenlock period; followed by marked diminution to 34 species in the Devonian, and a revival toward Silurian abundance in the Carboniferous. Thus the two periods of maximum development in this group were the Silurian and the Carboniferous; but these did not go on *pari passu* as between the different families. The Lecanocrinidae show a rapid decline from Silurian to Carboniferous, while the Taxocrinidae correspondingly increased, so that the aggregate of the two is not very different in the two epochs.

It is a singular fact that whereas the two known species of Flexibilia in the Ordovician are highly typical Taxocrinidae, the great development of the group which rapidly succeeded in the Silurian did not take place in this family at all, but in the Lecanocrinidae, which in their typical forms are farthest removed from it. This leads to the inference that the Lecanocrinidae developed through a different line of ancestors in the Ordovician, or earlier. Their structure, being that of a strong anal side and solid walls, is specialized in the direction of the Camerata, and the family ran its course from opulence to poverty and ultimate extinction very much as did the Camerata. The Taxocrinidae, on the other hand, represent the true Flexibilia type, comparable to stages in the ontogeny of the living crinoids, and its progress was one of steady increase to a maximum in the Mississippian, or Mountain limestone, period of the Lower Carboniferous, followed by extinction at the close of that age. Both the Sagenocrinidae and Ichthyocrinidae maintained a fairly even course, except for the entire absence of the former in the Devonian; this fact emphasizes the imperfection of the geological record in reference to this group, for the succession from the Silurian to the Carboniferous forms in this family is so evident that it is impossible to imagine an actual break; and it is to be hoped that some new Devonian locality will yet furnish the missing connection. The rapid rise and great expansion of the Flexibilia in the Silurian accord with the development among the other crinoids, as well as in many other forms of life which flourished abundantly in an age characterized by conditions favorable to most forms of shallow water life. Taken as a whole, however, the acme of the Paleozoic crinoids was attained in the Lower Carboniferous.

The American species of the Flexibilia exceed in number those from Europe by a proportion of 60 per cent against 40; the disparity is not so great as in the Camerata or in the Inadunata. The maximum of European species was reached in the Silurian, which has produced 42 out of the total of 71; less than a third of that number are from the Carboniferous. In America the Silurian species number 29, and the Carboniferous 57.

In the Silurian Flexibilia there is unquestionably a great similarity between the American and European faunas, which has been emphasized by the discoveries of recent years in this country. *Pycnosaccus, Anisocrinus, Clidochirus, Sagenocrinus, Protaxocrinus* and *Gnorimocrinus,* all formerly supposed to be strictly British or Swedish genera, now prove to be represented by good species in the American rocks; and of the three species of my new genus *Hormocrinus,* one comes from each of these countries. In the highly specialized and hitherto little known *Pycnosaccus,* of which I now have abundant new material, some of the specimens from Tennessee can scarcely be distinguished from those of Dudley and Gotland. Three rare and specialized European genera of the other orders have also been found in the American Silurian, among them the very remarkable *Crotalocrinus;* while the almost equally remarkable American form, *Petalocrinus,* has been discovered in Sweden. Of the 17 Silurian genera of the Flexibilia, all but one are represented in the European rocks, while 7 are unrepresented in America, most of them being extremely rare or local in their occurrence; thus 9 of the genera are common to both areas. Some of these facts (not all being before known), together with evidence of identity and close relationship in other faunas, have led to the opinion especially developed by Weller,[1] and afterwards supported by Chamberlin and Salisbury,[2] that there was a migratory connection between the Silurian faunas of northern Europe and the interior of America.

Of the 13 Carboniferous genera, 9 are common to both continents; all but one are represented in America, while 3 American genera are not found in Europe. The recent addition of the two specialized forms, *Amphicrinus* and *Onychocrinus,* to the list of genera common to both areas greatly emphasizes the resemblance of the two faunas, and accords with the opinion held by the later authorities in Paleogeography that in this age also, as in the Silurian, there was a migratory communication between the American and European continents by one of the northern routes.[3]

Of the 9 Devonian genera, 3 of which begin in the Silurian and 4 pass into the Carboniferous, 8 occur both in Europe and America; but there is little similarity in the species from the two continents, which is to a large extent true for the other orders of crinoids.

The development of the crinoids as a whole was greater in the Lower Carboniferous than in any other Paleozoic period. The physical conditions of the American continent during that epoch, with its extensive shallow seas and general prevalence of clear waters, were peculiarly favorable to the expansion of the crinoidal faunas, and this vast basin became so densely populated with these organisms that their calcareous remains constitute the greater part of the sedimentary deposits. The Mississippi valley was the center of this development, and it extended westward—its resulting strata now underlying the great plains area—into the Rocky Mountain region, where abundant evidence of its existence, with more or less migrational changes of species, is to be found from New Mexico to Montana, and westward as far as Nevada.

The rise, expansion and decline of the Flexibilia are in substantial accordance with those of the Paleozoic crinoids in general, viz., rapid development in the Silurian, recession in the Devonian, attainment of the acme in the Lower Carboniferous, followed by extinction near or shortly after the close of the Paleozoic.

The hitherto prevailing idea that the Crinoidea, as represented by their surviving order, the Articulata, are a dwindling race almost on the verge of extinction, must now be modified, in view of the great extension of knowledge of the Recent crinoids during the past few years, largely through the medium of the researches of Mr. Clark in the National Museum before alluded to upon American and foreign collections. Instead of only 12 genera and 212 species of Stalked crinoids and comatulids known at the date of P. H. Carpenter's monographs upon the collections of the "Challenger" expedition, there are now known 142 genera and 576 species, of which 123 genera and 343 species have been described by Clark alone; these are distributed among 20 families and 8 sub-families. The crinoids, therefore, constitute one of the richest and most varied faunas of the present seas, the extent and importance of which will continue to increase; for, notwithstanding the great acquisitions of the past dozen years due to the activities of numerous dredging expeditions maintained by different governments, the fact still remains that all these dredgings represent only the imperfect gleanings of a few out of the 140,000,000 square miles which the oceans cover. The number of crinoids existing in certain localities is amazing; as many as 10,000 have frequently been brought up by a single haul of the dredge. A. Agassiz[1] speaks of "a field of *Rhizocrinus*" growing on the sea bottom in the West Indies. At Singapore 24 species of crinoids have been taken within a radius of a few miles, a variety which is surpassed by but few localities of Paleozoic crinoids.

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[1] Journal of Geology, vol. 4, 1896, pp. 166-173; *ibid.,* vol. 6, 1898, pp. 692-703.

[2] Chamberlin and Salisbury, Geology, vol. 2, 1906, p. 410.

[3] *Ibid.,* p. 522.

It is somewhat remarkable how meager are the remains of fossil crinoids thus far known from other continents than Europe and America. A few have been reported from the Andes in South America; some of Jurassic age from China, from the islands of New Guinea, Misol and Roti, and from the Arctic regions. An interesting fauna, chiefly Carboniferous, has been described by Ratte and by Etheridge from Australia; Ordovician, Silurian and Devonian crinoids and cystids from India by Reed, and also a Carboniferous species by De Koninck. A more remarkable Echinoderm fauna has been discovered in the island of Timor, in the Dutch East Indies, some forms of which have been described by Beyrich, by Bather, and by Wanner; large collections have been made in recent years by the Dutch geologists headed by Dr. G. A. F. Molengraaff of Delft, and by Professor Wanner of Bonn. This fauna is said to be Permian, but I feel confident that, as already suggested by Bather, it will prove to be in part Lower Carboniferous. None of these outlying occurrences, to my knowledge, have thus far yielded any specimens of true Flexibilia.

The annexed table of Distribution furnishes a résumé of the occurrence of the Flexibilia throughout the recognized American time divisions and their approximate European equivalents, as well as within the two continents.

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[1] Three Cruises of the U. S. Coast Geodetic Survey Steamer "Blake," etc., from 1877-1880 [1888], p. 118.

### *Geological Distribution of the Flexibilia*

**Number of species**

(Open figures indicate American, those marked ( ) European)

| General | American | Approximate European Equivalents | Lecano-crinidae | Sageno-crinidae | Ichthyo-crinidae | Taxo-crinidae | American | European | Total |
|---|---|---|---|---|---|---|---|---|---|
| Carb. | Pennsylvanian | | ... | ... | 1 | ... | ... | ... | ... |
| Lower Carboniferous | Kaskaskia | Moscow<br>Hurlet | ...<br>... | ...<br>... | ...<br>(2) | 3<br>(1) | ...<br>... | ...<br>... | ...<br>... |
| | St. Louis | | ... | ... | ... | 3 | ... | ... | ... |
| | Warsaw | | ... | 2 | ... | 1 | ... | ... | ... |
| | Keokuk | | ... | 4 | 1 | 9 | ... | ... | ... |
| | Burlington | Mountain limestone | 8(1) | 2(1) | 9(4) | 5(3) | ... | ... | ... |
| | Kinderhook-Waverly | | ... | 1 | 1 | 7 | ...<br>57 | ...<br>(12) | ...<br>69 |
| Devonian | Chemung, Portage | Upper | ... | ... | (2) | 5 | ... | ... | ... |
| | Hamilton | Middle | 1(1) | ... | 4(1) | 5(2) | ... | ... | ... |
| | Helderbergian | Lower | 2(1) | ... | 3 | 1(6) | ...<br>21 | ...<br>(13) | ...<br>34 |
| Silurian | Niagaran | Wenlock | 18(22) | 2(8) | 4(7) | 3(5) | ... | ... | ... |
| | Medinan | | ... | ... | 1 | 1 | ...<br>29 | ...<br>(42) | ...<br>71 |
| Ordovician | Trenton | Caradoc | ... | ... | ... | 2 | 2 | ... | 2 |
| | American species | | 29 | 11 | 24 | 45 | 109 | | |
| | European species | | (25) | (9) | (16) | (17) | ... | (67) | |
| | Total species | | 54 | 20 | 40 | 62 | 109 | (67) | 176 |

## CLASSIFICATION

In the North American Crinoidea Camerata by Wachsmuth and myself,[1] there was given a historical résumé of the principal writings upon the crinoids, and a discussion of the various plans of classification put forth from time to time by different authors. It is not my purpose in the present treatise to retrace the steps there taken, nor to deal with those subjects anew, except to supply some matters not sufficiently covered before, and to bring the question of classification down to date in the light of researches and publications since the appearance of that work.

In the history of opinion as to the nature and relations of the crinoids sufficient credit was not given by us to the pioneer work of Edward Llhuyd (Luidius), Head Keeper of the Ashmolean Museum at Oxford,[2] who was the first author to notice the intimate relationship between the fossil Crinoidea and the living comatulid now known as *Antedon bifida.* This he did, as W. B. Carpenter has justly said, "not as a mere guess, but on the sound basis of anatomical correspondence," with an accuracy and discrimination which stamps him as an observer and thinker far in advance of his contemporaries.

Of the classifications of the Crinoidea into large divisions the two which have had the greatest influence upon the knowledge of this group of Echinoderma are undoubtedly those of J. S. Miller[3] and Johannes Müller.[4]

Miller's classification is important first of all because he was the earliest author who undertook to treat in a systematic way the Crinoidea as a class. This class was limited by him to the stalked, brachiate crinoids, thus excluding from consideration forms now known as cystids and blastoids which he did not discuss at all, and *Marsupites* and the Comatulae which he placed among the "Stelleridae." The comatulids, which, since J. V. Thompson's epoch-making discovery of the young in 1827, and of the connection between the young and the adult in 1835, have been known to be stalked in their young or "pentacrinoid" stage, were logically included in his definition, and are so treated by all modern authorities; Miller himself noted their resemblance to the crown of *Pentacrinus,* and called attention to the fact that the plate at the base of the calyx of the Comatulae occupies the same position as the first columnal of the Crinoidea.

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[1] Mem. Mus. Comp. Zoology, Harvard, vol. 20, 1897, pp. 11-31, 144-161.

[2] Lithophylacci Britannici Ichnographia, 1699, pp. 44, 101; Edition 1760, p. 145.

[3] A Natural History of the Crinoidea, 1821.

[4] Bau des *Pentacrinus caput-medusae,* Monatsber. Akad. Wiss. Berlin, Apr. 1840, pp. 88-106; Wiegmann's Archiv., 1840, pp. 307-318; Abhandl. Konigl. Akad. Wiss. for 1841, pub. 1843, pp. 177-248; separate, pp. 1-72.

Miller, although not in very clear terms, took as the chief basis of his general classification the mode of union between stem and calyx and between calyx and arms; and upon this character he subdivided the Crinoidea into four primary groups comprising nine genera, all but two of which were at the same time proposed by himself. These were (1) ARTICULATA: *Apiocrinites, Encrinites, Pentacrinites;* (2) SEMIARTICULATA: *Poteriocrinites;* (3) INARTICULATA: *Cyathocrinites, Actinocrinites, Rhodocrinites, Platycrinites;* and (4) COADUNATA: *Eugeniacrinites.* The first of these included most of the Mesozoic and Recent crinoids; the second and third the then known Paleozoic genera of what are now the Camerata and Inadunata. His primary groups, except the first, have not survived; but his generic names are among the classics of crinoid literature, and have been utilized for the designation of well-grounded family divisions.

The so-called classification of Johannes Müller has been given a prominence in subsequent treatises somewhat disproportionate to its merits, due no doubt to the great and deserved reputation of this distinguished man as an anatomist. The structure and embryology of the various types of the Echinoderma attracted his earnest attention, resulting in a series of memorable researches which formed both a foundation and a model for all future work of that kind. He did not undertake the systematic study of the Crinoidea, nor did he propose a formal classification; but incidentally, in connection with an anatomical study of the West Indian stalked crinoid, "*Pentacrinus caput-medusae*" (*Isocrinus asteria*), he assigned family names to certain forms or groups as they came up for consideration. The first of these (under the same name) was essentially the Articulata of J. S. Miller, with the Comatulae added—containing crinoids with free rays rising above the joining membrane. The second, Tessellata, without any very accurate definition, included Miller's Semiarticulata and Inarticulata plus some additional genera of similar type, and also *Marsupites.* These two embraced all then known crinoids except three genera, each of which he thought should be placed in a different family. For *Saccocoma* he proposed "Costata"; for *Haplocrinus,* "Testacea"; while *Holopus* was left without other designation. He considered the "stalked crinoids without arms, as the *Pentremites* and *Sphaeronites*" to form two families, but did not propose for them any additional names. Müller gave a list of genera as examples of his family Tesellata, and it is interesting to note that among the Paleozoic crinoids included by him and by J. S. Miller in their respective families there is not a single genus belonging to the order Flexibilia, which forms the subject of the present work.

Bronn[1] in 1860 adopted the three divisions, Articulata, Tessellata, and Costata, upon the authority of Johannes Müller (though without any credit to

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[1] Klassen und Ordnungen des Thier-Reichs, p. 228.

Miller for the first), including among the Tessellata the principal representative genera of the present Flexibilia, *Taxocrinus, Lecanocrinus, Forbesiocrinus* and *Ichthyocrinus,* which had in the meantime been established.

In 1879 von Zittel[1] also took up the Müllerian families,—Tessellata, Articulata and Costata, ranking them as suborders of the Crinoidea. None of these authors, however, had given a clear definition of the chief diagnostic character of the Articulata, and it remained for P. H. Carpenter to do this in the "Challenger" Report on the Stalked Crinoids, pp. 145, 146, where he said "the name-giving difference between the Articulata and the Tessellata is reduced to a supposed difference in the mode of union of the first radials with the joints which they bear."

In 1877 Wachsmuth,[2] in a profound analytical study of their structure, laid the foundation for the general classification of the crinoids which in its essential features has been maintained in our joint and several works ever since. He distinguished among the Paleozoic crinoids three general plans of structure: The *Taxocrinus* plan (Taxocrinidae); the *Cyathocrinus* plan (Cyathocrinidae); and the *Actinocrinus* plan (Spheroidae). These were elaborated in our Revision of the Palaeocrinoidea, 1879-1886, under the respective corresponding divisions Articulata, Inadunata (Larviformia plus Fistulata), and Camerata, differentiated by the mode of union between the calyx plates, and the condition of the arms, whether free above the radials or partly incorporated into the cup. The Articulata were treated under a single family, the Ichthyocrinidae.

In our Monograph of the North American Crinoidea Camerata, 1897,[3] we adhered to the same divisions, with a change, however, in regard to the Articulata, which was made to include not only the Paleozoic Ichthyocrinidae under the subdivision Articulata Impinnata, but the Mesozoic and Recent Apiocrinidae and Comatulae, as Articulata Pinnata. This arrangement was partly based upon the idea that the growth of the stem in these forms proceeded by the interpolation of new ossicles beneath the top columnal instead of next to the calyx; so that, as there expressed, the "top stem-joint is not the youngest joint in the stem." It has long been evident to me that too much importance was attached to this supposed feature, which was largely hypothetical as to Paleozoic forms, and the existence of which as a fixed character is disproved by my subsequent observations on some of the very forms in which it was thought to be most prominent.

Von Zittel in his Grundzüge der Palaeontologie, 1895, adopted in principle the classification of Wachsmuth and Springer in regard to the Paleozoic crinoids, using for the first three orders the names Larviformia, Camerata and Fistulata; for the fourth (=the Articulata of Wachsmuth and Springer, *non* Müller) the name Flexibilia; and for the fifth the name Articulata *sensu* Johannes Müller, including the Mesozoic and Recent crinoids. The Flexibilia he subdivided into the families Ichthyocrinidae Wachsm. u. Springer, Marsupitidae D'Orb., and Uintacrinidae Zittel.

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[1] Handbuch d. Palaeontologie, p. 341.

[2] Internal and External Structure of Palaeozoic Crinoids, Amer. Jour. Sci., vol. 14, Aug. 1877, pp. 184-6.

[3] See pp. 150 *et seq.*

In 1898, Bather[1] at the meeting of the British Association brought forward his proposal for a Phylogenetic Classification of the Pelmatozoa, which was further developed in his chapters on the Echinoderma, published as Part III of Sir Ray Lankester's Treatise on Zoology. For depth of research, comprehensiveness of plan, aptness of illustration, and clarity of statement, I do not hesitate to place this work of Bather's at the head of all general treatises on the crinoids. The labor involved in its preparation was enormous; for the work, while embodying the results attained by previous authors, is in no sense a compilation, but is replete with masterly original research. No other treatise approaches it in practical usefulness to the student of the crinoids and related forms; no other one has been so much and so profitably used by me in connection with my own later researches; and the fact that we do not agree in some of our conclusions in no wise detracts from my high estimation of this admirable work.

The chief point upon which we disagree is the broader aspect of the classification of the Crinoidea, which we have approached from different points of view. He has been good enough to say that although not the phylogenetic classification sought by the modern biologist, the system of Wachsmuth and Springer is " far the best from an anatomical standpoint."

Bather attaches primary importance to the construction of the base, whether dicyclic or not; and upon the presence or absence of infrabasals he divides all crinoids into the two sub-classes, Monocyclica and Dicyclica. Subject to these more comprehensive divisions he retains the Camerata (minus the Platycrinidae and Hexacrinidae which he separates under the Adunata), the Inadunata, and the Flexibilia as subdivisions under his larger groups. His chief subdivisions are: Under Sub-class I—Order 1, Monocyclica Inadunata; Order 2, Monocyclica Adunata; Order 3, Monocyclica Camerata. Under Sub-class II—Order 1, Dicyclica Inadunata; Order 2, Dicyclica Flexibilia (Grades Impinnata and Pinnata); Order 3, Dicyclica Camerata. Thus the differences between us in the main are rather relative than positive, as for example, whether we should say " Monocyclica camerata," or " Camerata monocyclica." His opinion that the dicyclic or monocyclic base are characters of more comprehensive significance than any others within the class has been fortified by cogent arguments which are entitled to the greatest consideration.

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[1] Rep. British Assoc. for 1898 (Bristol), pub. 1899, pp. 916-923.

In the meantime Jaekel[1] had essayed a classification upon phylogenetic grounds, which he applied in his subsequent important monograph upon the Stammesgeschichte der Pelmatozoen, 1899. He, likewise, criticised the plan of Wachsmuth and Springer because, in his opinion, they had dealt with the morphological conditions as they found them too much from an anatomical standpoint, and had not sufficiently taken into account the import of the modifications due to descent.

We have, therefore, two new and almost simultaneous phylogenetic classifications, by two of the most eminent living authorities, both predicated in part upon the insufficiencies of Wachsmuth and Springer's system, and each believed by its author to be an approximately correct reading of the race history of the crinoids, according to the principles of modern Biology. But instead of a concurrent result of the application of those principles, it appears that the two classifications are about as fundamentally and diametrically opposed as any two things could be.

Bather, as already stated, finds in the presence or absence of infrabasals ground for a primary division of the Crinoidea into two sub-classes, independently developed from unknown ancestors, viz., Monocyclica and Dicyclica, of which the Camerata and Inadunata are only subordinate divisions found in each of the primary groups; and he splits the Camerata into two groups because he thinks the Platycrinidae and their allies depart too widely from the typical form.

Jaekel, on the other hand, does not recognize in the dicyclic or monocyclic base a ground for large divisions at all. But he considers the Camerata a division of even higher rank than its authors supposed, and accordingly erects it into a sub-class under the name Cladocrinoidea, which he separates from all other crinoids because he believes its representatives descended independently from some of the many-plated cystids; and the Platycrinoids he firmly retains within this group. The remainder of the crinoids he groups in a sub-class of equal rank with the Camerata, under the name Pentacrinoidea, within which he places the Fistulata (W. and Spr.); Larvata (Larvifromia W. and Spr.); Costata; Articulosa (Articulata, W. and Spr.); and Articulata (W. and Spr.; Müller). Monocyclic and dicyclic forms occur indiscriminately throughout each of his basic groups.

It is not my purpose at this time to undertake a discussion of the merits of these two conflicting plans. The evidence upon which a final summing up can be made is not yet in hand. It is my expectation, if time suffices, to follow the present work with a similar treatment of the remaining group of Paleozoic and partly Mesozoic crinoids, the Inadunata, in the hope that the necessary facts may thus be fairly marshalled as material for future discussion by some one of the status and relationship of the subdivisions of the Crinoidea. In the meantime, in view of the widely divergent results attained by the application of phylogenetic principles in the two later classifications, I feel content to stand upon the general features of the plan of Wachsmuth and Springer regarding the Paleozoic crinoids, with some modifications in detail suggested by newly acquired knowledge; returning, however, to the Articulata of Miller and Müller for the Recent and most of the Mesozoic crinoids. Accordingly we shall have the following table for expressing the—

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[1] Sitzungs-Bericht Ges. Naturf., Berlin, Apr., 1894, p. 101.

## PRIMARY DIVISIONS OF THE CRINOIDEA

Crinoids with a rigid calyx in which the lower brachials are to a varying extent firmly incorporated into the dorsal cup, being rendered fixed and immovable by union either with dorsal or ventral structures. Plates of the calyx united by close suture. Mouth and calyx food-grooves chiefly subtegminal. Subject to modification as to either character in transition forms. Arms pinnulate. Order............CAMERATA.

Crinoids with a flexible calyx in which the lower brachials are loosely incorporated into the dorsal cup either by lateral union with each other, by means of interbrachials, or of a skin studded with calcareous particles. All plates beyond the radials united by loose suture, and more or less movable. Mouth and tegminal food-grooves exposed. Arms non-pinnulate. Order............FLEXIBILIA.

Crinoids with rigid calyx in which the brachials are free (or sometimes loosely connected) above the radials. Plates of the calyx united by close suture. Mouth sub-tegminal; food-grooves supra-tegminal, but may be closed by fixed ambulacral plates. Arms pinnulate or non-pinnulate. Order...........INADUNATA.

Crinoids in which the mode of union of the radials with the plates they bear is by complete muscular articulation, and in which are combined certain additional characters stated below. Arms pinnulate. Order...........ARTICULATA.

The Camerata were a highly specialized group, confined to the Paleozoic, and becoming extinct in the Lower Coal Measures. Within this group occurred various modifications of base, anal structures, and arms, affording criteria for the sharp differentiation of families, but all subordinate to the general type of a solidly enclosed calyx, combined with the absence of, or a restricted, movement of the brachials upon the radials. There is, of course, in some forms more or less of a tendency to modification of these characters in the direction of other groups, as among the Platycrinoids, where there is often but slight incorporation of the brachials, or none at all, in the dorsal cup. In these cases, however, there is usually a very definite restriction in the mobility of the brachials upon the radials by means of rigid adambulacral and covering plates. Any proposal for segregating the Platycrinoids and Hexacrinoids into an independent group upon this character would be nullified by the many important exceptions formed by cases in which the first brachial is completely incorporated, either by interbrachials alone (*e. g.*, the form called *Brahmacrinus* by Sollas, and certain species of *Platycrinus*); or by means of other brachials which overlap the first and make it rigid (*e. g.*, *Marsipocrinus*, *Pterotocrinus*, etc.). Or, the modification may be towards a more flexible calyx as in the Reteocrinidae, in which, however, the mouth and food-grooves are strictly subtegminal. Such cases, in my opinion, must be treated as intermediate types, transitions toward the Inadunata and Flexibilia respectively, which upon a fair preponderance of the characters seem to go better within the Camerata than anywhere else. Whether to leave them so, or to create independent divisions for them, is a matter of expediency depending upon the individual point of view.

The Flexibilia are also specialized, and were similarly limited to the Paleozoic, though there is a sporadic reappearance of some of their characters among the Apiocrinidae and the comatulids. The Inadunate type, representing the most generalized structural plan of the crinoids—a calyx composed of basals, radials and orals, which at some stage forms the entire calcareous skeleton above the stem in every crinoid—is in its most essential features, though variously modified, carried forward with the Articulata, and thus has an unbroken range from the earliest Ordovician to the present time. These three groups underwent more or less parallel modifications, with analogous differentiation of characters for family divisions, some of which reappeared independently in each of them.

The Articulata, with their Neozoic range from Jurassic to Recent time, present an aggregate of characters which seem to indicate a separate group, broadly comparable to the other three but upon somewhat different criteria. This method of treatment is a departure from the later plan of Wachsmuth and Springer by way of a return to the earlier one, now reinforced, as it seems to me, by more substantial reasons than before; it has already been briefly suggested by me in the new edition (1914) of the Zittel-Eastman Textbook of Palaeontology. This view also accords with the conclusion reached by Dr. Kirk as the result of independent researches on Certain Eleutherozoic Pelmatozoa,[1] as follows:

> Among all the known post-Paleozoic Crinoidea there is an essential unity of structure that points strongly to a not widely diverse origin.

The chief characters relied upon to distinguish this order as extended and defined by Müller, viz.: (1) an open mouth and food-grooves, and (2) a separate axial or dorsal canal perforating the arms, were clearly indecisive, considering that the first belongs equally to the entire Paleozoic group Flexibilia, and the second is shared by a Devonian family and several genera of the Inadunata.

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[1] Proc. U. S. Nat. Mus., 41, 1911, p. 81.

This evident inadequacy of the definition has led to various proposed remedies, such as placing the Pentacrinidae under the Fistulate Inadunata, and the comatulids together with the Apiocrinidae as a subdivision (Pinnata) under the Flexibilia. None of these has proved satisfactory, least of all the last, for the lack of any sufficiently definable connection between the so-called Pinnata and the Paleozoic Flexibilia. It is true the pliant calyx of the latter recurs in the pelagic comatulids, *Marsupites* and *Uintacrinus,* and the close lateral union or partial incorporation of lower brachials is found to some extent among the Apiocrinidae, Pentacrinidae, and some comatulids. But it has become increasingly evident that the Flexibilia were a specialized group, derived from the Inadunata, and ending like the Camerata with the Paleozoic.[1]

While there is no valid ground for any such divisions as Palaeocrinoidea and Neocrinoidea, as proposed by Wachsmuth and Springer and by Carpenter, and afterward abandoned, yet it cannot be denied that with the exception of the Triassic *Encrinus* and the Plicatocrinidae the known crinoids of Mesozoic to Recent time have an assemblage of features by which they are broadly distinguished from their Paleozoic ancestors. It is believed that this may be expressed under the group Articulata as enlarged by Johannes Müller, distinguished not by any single character peculiar to itself, but by the fact that a large number of characters belonging to different groups of Paleozoic crinoids, and by which they were differentiated, have become associated, fixed and generally constant in this. It is by the combination of the following characters, therefore, that the definition of this group, as herein given, becomes logically effective:

1. The predominance of the stem as a source of differential characters. In the older crinoids the modifications marking the larger divisions occurred wholly in the calyx, and with the culmination of these calyx modifications the types themselves became extinct. In the survivors the general type of calyx became more fixed by decrease in size and the consequent elimination of disturbing elements, while the larger changes in the structure of the class took place in the stem and its attachments, which furnish the chief characters for the later major groups.
2. The mode of union of the radials with the plates they bear by complete muscular articulation. This was the character chiefly relied upon by Müller, and while subject to modification or exception in a few genera, and to loss in senile stages of living forms, it holds good throughout the group. And this is also the strongest character of the latest surviving family of the Paleozoic crinoids, which passes on to the Triassic,—the Poteriocrinidae.
3. Open mouth and food-grooves.
4. Axial or dorsal canals extending into the arms within the calcareous substance of the plates.
5. The uniserial, and complete absence of biserial, character of the arms.

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[1] The nearest approach to a relation between this group and the later crinoids has been worked out by Mr. Clark, in connection with the second part of his Monograph now in preparation; he finds in the larval stage of the Recent comatulids before the appearance of the first pinnules and of the cirri, and in that stage only, remnants of the ancestral structure of the Palaeozoic Flexibilia.

6. The general prevalence of regularly spaced syzygies.
7. The constant presence of pinnules; the first two segments of which are always differentiated from those succeeding.
8. The general absence of a concave base.
9. The general presence of a modified top columnal, or proximale.
10. The general absence of bilateral, and prevalence of pentamerous, symmetry, modified only by tegminal characters and by loss or addition of rays, and not by anal structures in the dorsal cup.

The type of Crinoidea now constituting the order Flexibilia was not recognized as the basis for a major group by any author prior to 1877. There is little doubt that if Johannes Müller had been better acquainted with its essential characters he would have perceived its importance in the structure of the crinoids, for in his list of genera in the Abhandlungen, 1843, p. 208, he noted under *Poteriocrinus nobilis* and *P. egertoni* that they "belong not to the genus *Poteriocrinus*." Phillips about the same time, and independently, observed the peculiar habitus of these and allied species, and considered it sufficient ground for the creation of a new genus, for which he proposed in 1841 the preoccupied name, *Isocrinus*,[1] and in 1843 *Taxocrinus*.[2] The Austins[3] in 1842, in their proposed Arrangement of the Echinodermata into Families, placed Phillips's genus under the Poteriocrinidae.

Quenstedt, in the various editions of his Handbuch der Petrefactenkunde, 1852, 1867, and 1885, and also in his Petrefactenkunde Deutschlands, 1874-1876, ranged *Taxocrinus, Ichthyocrinus* and their allies under the Cyathocriniden, or Cyathocrinen.

Roemer[4] in 1854 included most of the then known genera of this group under his family Cyathocrinidae, disregarding entirely the important work of Phillips, and suppressing his genus *Taxocrinus* as a synonym of *Cyathocrinus*. He was the first author to call attention to the tegmen as a character for classification, and he grouped the Stalked crinoids into two sections, which he left without names, as follows: *a*. Ventral side consisting of a soft skin; *b*. Ventral side covered by solid immovable plates. In the first he placed the Recent and Mesozoic crinoids, plus the Cupressocrinidae and his Cyathocrinidae (which included representatives of all the present Paleozoic orders); and in the second the Poteriocrinidae and all the other Paleozoic crinoids. He proposed Sagenocrinidae as one of his 21 families for the reception of the single genus, *Sagenocrinus*,—being the first family name used exclusively for crinoids of this type, although without any perception of its true characters.

Pictet[5] in 1857 distributed the genera indiscriminately among his three groups, Cyathocriniens, Actinocriniens, and Carpocriniens.

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[1] Palaeozoic Fossils of Cornwall, pp. 29-30.

[2] In Morris, Catalogue of British Fossils, p. 90.

[3] Ann. and Mag. Nat. Hist., vol. 10, pp. 106-110.

[4] In Bronn, Lethaea Geognostica, 3d edition, vol. 1, pt. 2, p. 227.

[5] Traité de Palaeontologie, pp. 314-330.

The earliest definite recognition of the taxonomic value of the fundamental structure upon which the present order Flexibilia is based was by Wachsmuth in 1877,[1] when he proposed the name Taxocrinidae for one of the three groups into which he thought the Paleozoic crinoids would fall. He noted as its special characteristic the curved sutures between the plates of the radial series, of which he said: "This . . . . is conspicuous in the radials, thus producing apparently an articulate structure of the whole skeleton, and indicating some degree of flexibility in the body as well as the arms." As to the summit, or vault, which had not then been found preserved, he did not think it consisted of a soft skin, but from fragments he had seen inferred that the disk was covered by very small plates forming a "kind of scaly integument which was pliant and flexible" (*op. cit.*, p. 185). Wachsmuth criticised Roemer's course in including the Cyathocrinidae and Cupressocrinidae in his section *a*, with vault consisting of a soft skin, he insisting that on the contrary these two families belonged in a group by themselves having the vault covered by an immovable arch of small plates.

Angelin[2] in 1878 independently used the name Taxocrinidae as one of the 11 families under his section Trimera, placing the other Flexible crinoids under the families Sagenocrinidae, Homalocrinidae and Ichthyocrinidae. He did not propose any larger group for these forms, but divided the crinoids into general sections founded upon the number of basals.

Wachsmuth and Springer[3] in 1879 first treated the group systematically, under the name Ichthyocrinidae (which they substituted for Wachsmuth's Taxocrinidae), giving full diagnoses of the 11 genera then recognized, with bibliographic lists of the species. The definition took note of the presence of three "underbasals," and of the absence of pinnules, but emphasized as the leading character the "peculiarity of structure which prevails throughout the rays and arms . . . ," which "produces what seems to be an articulate structure in the whole skeleton, and indicates that the body as well as the arms was somewhat flexible" (p. 31). The pliant nature of the tegmen (vault) was inferred from that of the dorsal parts, and from the indications observed in fragmentary specimens. With rather inconsistent reasoning it was insisted that the vault, although pliant, was composed of solid plates, this being a necessary corollary of the assumption that all Paleozoic crinoids—then designated as the Palaeocrinoidea—were distinguished from the Mesozoic and Recent crinoids by having the "oral side closed by a more or less solid integument without external food-grooves or oral aperture" (p. 30). It remained for future years to bring forth the capital discovery, confirmatory of the independent rank of this group, that it has an open mouth and exposed food-grooves like the Recent crinoids.

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[1] Amer. Jour. Sci., vol. 14, p. 185.

[2] Iconographica Crin. Sueciae, p. 8.

[3] Revision of the Palaeocrinoidea, pt. I, p. 30.

In von Zittel's Handbuch der Palaeontologie, 1879, the Taxocrinidae and the Ichthyocrinidae were listed simply as two of 26 families under the suborder Tesellata. But in his Grundzüge der Palaeontologie, 1895, he adopted in substance the primary divisions of Wachsmuth and Springer, substituting, however, for their Ichthyocrinidae the obvious and appropriate name suggested by Wachsmuth's original definition, the FLEXIBILIA.

In 1888 Wachsmuth and Springer[1] discovered the tegmen, or vault, in a specimen of *Taxocrinus intermedius,* in so perfect a condition as to leave no doubt whatever as to the complete differentiation of this type from that of the other groups of Paleozoic crinoids. Consistently with the flexible calyx, it proved to have an integument of pliant perisome, with exposed food-grooves passing over it between parted oral plates into a central open mouth. This discovery thoroughly fixed the status of the order now called Flexibilia as an independent group, and it has been since confirmed by the discovery of similar tegmens in another species of *Taxocrinus,* and in *Onychocrinus, Synerocrinus, Homalocrinus* and *Pycnosaccus,* representatives of three of the families into which the order is divided.

Induced by this unexpected anatomical similarity to the Recent crinoids, we undertook in the paper last cited to attach the name Articulata to this group, and in our later work on the Crinoidea Camerata we proposed to include within it the Apiocrinidae and Comatulae as Articulata Pinnata, while the non-pinnulate paleozoic members would constitute another section called Articulata Impinnata. The use of the name "Articulata" in this sense was admittedly questionable, and it was suggested that "Articulosa" of Jaekel might be adopted as an alternative. The text of our work was completed in 1894. Owing to the protracted illness of Wachsmuth, and the engrossing business cares of the present writer, we did not keep in touch with current literature while it was passing through the press, and therefore the peculiarly apt term "Flexibilia," employed by von Zittel in 1895, was overlooked. Had it been known to us, the text would have been corrected in the proofs so as to utilize it.

In the Lankester Treatise on Zoology, 1900, Bather adopted the term "Flexibilia" as equivalent to the Articulata of Wachsmuth and Springer, not Müller, and with it the two subdivisions Impinnata and Pinnata. He arranged the Impinnata under five families: Ichthyocrinidae, Gazacrinidae, Taxocrinidae, Dactylocrinidae and Sagenocrinidae. As to these he said: "The genera seem to merge into one another, and are as yet too ill-defined to be grouped into families on a sure genetic basis" (p. 187). His Gazacrinidae was proposed under a misapprehension of the rather obscure genus *Gazacrinus,* which is a Camerate crinoid with biserial pinnulate arms, as has been proved by excellent undescribed material since discovered.

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[1] Discovery of the Ventral Structure of *Taxocrinus,* Proc. Acad. Nat. Sci. Philadelphia, for 1888, pp. 337-363.

In 1902,[1] having discovered the presence of the radianal in *Sagenocrinus* and *Temnocrinus,* I suggested a tentative arrangement of the Flexibilia into two families, Ichthyocrinidae and Taxocrinidae, based upon the general form of the crown, and the character of the arms, whether contiguous or divergent.

Special study of this group with a view to the present work resulted in the acquisition of material information regarding the true structure of hitherto obscure genera, as well as newly discovered characters in others, and a preliminary notice of some of these results was given in 1906.[2] The discovery of the radianal in *Ichthyocrinus,* hitherto supposed to have a perfectly pentamerous calyx, and in certain Taxocrinoid forms; of the actual relations of the Silurian genera *Anisocrinus, Clidochirus, Homalocrinus* and *Calpiocrinus;* and of certain definite modifications of characters from Silurian to Carboniferous time; led to a considerable increase in the number of genera, and to a more logical basis for their arrangement into families. A further tentative classification was proposed, by which the group was divided into three families, Ichthyocrinidae, Sagenocrinidae, and Taxocrinidae, based primarily upon far reaching differences in the anal structure, and secondarily upon the degree of contact or separation of the rays due to the presence or absence of interbrachial plates.

Continuation of my researches since that time has brought further increase of knowledge, by means of which the subdivisions of the group, while in general features similar to those of 1906, are placed, as it is hoped, upon a sounder basis. The following definition is believed to express the results of all the evidence tending to establish the Flexibilia as a morphological unit:

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[1] American Geologist, vol. 30, pp. 88-97.

[2] Journal of Geology, vol. 14, pp. 467-523.

### Order FLEXIBILIA Zittel

Crinoids in which the lower brachials are loosely incorporated in the dorsal cup, either by lateral union with each other, by interbrachials, or by a finely plated skin. Base dicyclic; infrabasals three, unequal, exceptionally fused, often greatly reduced or atrophied; sometimes fused with the top columnal. Radials and brachials united by a modified muscular articulation, usually without transverse ridge, accompanied by loose suture between other plates, producing a flexible calyx admitting motion between apposed faces of the plates. Arms non-pinnulate, uniserial, with a wide and shallow ventral groove. Tegmen flexible, with exposed calcified ambulacra, roofed with movable covering plates; mouth supra-tegminal and open. Orals small, asymmetrical, with food-grooves passing between them to the mouth; the posterior one much the largest and probably a madrepore; they are more or less surrounded by perisome, which often passes down between the rays. Stem circular; proximal columnals usually very short, frequently wider than the others and forming a conical expansion next to the calyx; cirri usually wanting, or confined to the distal part of the stem as branching rootlets.

Geological range: Ordovician to Lower Coal Measures.

The Flexibilia form a compact, well-defined group, limited to the Paleozoic. They range from the earlier Ordovician (Trenton group) to the close of the Lower Carboniferous, with a single genus passing into the Lower Coal Measures. There is a general tendency from irregularity to regularity in the calyx structure; the radianal, which is well developed in the lower positions in the Ordovician and Silurian genera, becomes less conspicuous or disappears in the Carboniferous. The calyx and arm plates are usually thick and relatively short, with an imperfect muscular or loose ligamentous articulation which admits of much mobility. The combination of massiveness with flexibility is a remarkable feature in the structure of the calyx wall. The union between brachials is frequently marked exteriorly by arcuate sutures, produced by a downward projection of the outer proximal edge of the plates into a corresponding depression on the distal edge of those preceding; this extends but little below the surface, the sutures beneath being perfectly straight. By contraction in fossilizing the thin projecting processes are frequently fractured, giving rise to the erroneous idea of "patelloid plates."

Owing to the fact that in most of the genera the rays are more or less continuous from the radials up, with little differentiation between calyx and arms, there is a general similarity of type which renders the subdivisions of the group less apparent than in the Camerata. The most prominent modification of the general type relates to the construction of the posterior interradius, upon which two well-defined divisions may be recognized: (1) the strong anal side, in which the anal plates, when present, are partly or wholly incorporated in the calyx wall; (2) the weak anal side, in which the anal plates are separated from adjoining brachials at one or both sides by a calcareous skin, and tend to form a flexible series supporting the anal tube, which is a mere extension of the pliant perisome of the tegmen. The second of these structures is analogous to that found in the larval stage of the living crinoids; it is the most generalized, appearing in the Ordovician and ending with the culmination of the group at the close of the Lower Carboniferous. The first is more specialized, and so far as known began in the Silurian, continuing also to the end of the group; within it modifications in the size and position of the infrabasals, and in the general habitus of the calyx, afford ground for family divisions which shade into one another to some extent.

Among the genera of each section may be observed a migration of the radianal, from a primitive position directly underneath the right posterior radial (as if the radial were transversely bisected) in the older formations (Ordovician and some Silurian), to an oblique position at the lower left of the radial (some Silurian and Devonian), and then to an upper oblique position or complete elimination in the Carboniferous. Modifications in the number of primibrachs, by increase from two to three or more, were also to some extent coincident with these changes. The structure of the base remains remarkably constant, the proximal circlet consisting of three unequal infrabasals, which are exceptionally fused into an undivided discoidal plate, and in certain genera tend to disappear by atrophy.

As a result of the foregoing considerations the Crinoidea Flexibilia fall into two general groups, based upon the construction of the posterior interradius: A, represented by such forms as *Sagenocrinus;* and B, represented by *Taxocrinus.* These, which may for convenience be said to represent the strong and the weak calyx respectively, will take rank as suborders, characterized as follows:

A. With a strong calyx: SAGENOCRINOIDEA. This group includes all forms in which the posterior interradius either is not differentiated, or is more or less occupied by anal plates usually not in the form of a tube, the first plate of which is to any degree incorporated in the calyx; that is to say, is suturally united with adjacent brachials for at least part of its height on both sides. A genus like *Sagenocrinus,* in which the anal interradius is an enlarged copy of the others and forms a continuation of the solid calyx wall, will of course be a perfectly evident typical example of this structure. In a general way this group stands for a calyx with solid wall all around, as opposed to one in which the wall is weakened by the interposition of an anal tube at the posterior side. There are exceptions and intergradations in regard to this feature, as in all such cases; and it is difficult to frame a definition fixing an exact limit which will hold good everywhere. I have drawn the line at the first plate of the anal series above the posterior basal—the anal *x* as commonly designated. If this plate is free from sutural attachment at least on one side, it cannot be said to be incorporated in the calyx, and a form so constructed will not belong to group A. On the other hand there will necessarily be some genera which upon the criterion here given must be placed in group A, notwithstanding the fact that they may have a very apparent anal tube which would seem to throw them into group B. Such are intermediate forms like *Synerocrinus* and *Meristocrinus,* the systematic position of which must be decided upon a slight preponderance of evidence among characters more or less contradictory. This group also includes, in addition to those with a solidly filled anal side, such genera as *Ichthyocrinus, Metichthyocrinus, Wachsmuthicrinus* and *Nipterocrinus,* in which the posterior basal is not differentiated, and there are in the calyx (except the inconspicuous radianal in *Ichthyocrinus*) no anal structures whatever.

B. With a weak calyx: TAXOCRINOIDEA. This will include all forms in which the posterior basal is followed immediately by a tube-like series of plates no part of which is fully incorporated in the calyx, but which is bordered on one or both sides by perisome, and so to that extent separated from the adjacent brachials. In all genera composing this group, without exception, the posterior interradius is differentiated from the others by the interposition of an anal tube. The crown in genera of both groups may be weakened by the presence of a pliant perisomic integument instead of suturally united interbrachials above the zone of the radials in all the interradii, but in this group such perisomic integument is always to be found at the anal side between the posterior radials and down to the basal, whatever the structure may be elsewhere. Some exceptional intermediate forms in which this condition is closely approached are placed in the first group upon the weight of other characters.

The two divisions thus defined are substantially the same as those proposed by me in 1906 (Jour. Geology, vol. 14, p. 513), and further investigation has shown that the differences between them are even more striking and fundamental than was before supposed. Taking as typical of the two types of structure the genera *Forbesiocrinus* and *Taxocrinus,* which have been often confounded in the literature:

In *Forbesiocrinus* the posterior basal is angular or truncate above, and the distal face is united to the succeeding plates by powerful ligamentous connections of the same type as that between the basals, radials and primibrachs (Pl. XXI, figs. 1, 2, 3). The succeeding plates of the anal side are similarly united to adjacent brachials and to each other, the junction being marked by distinct zig-zag lines. The lateral faces of the brachials which abut on the posterior interradius are angular for a greater or less distance, and exhibit surfaces for sutural attachment to interbrachials of one kind or another high up between the rays. Hence the anal plates form an integral part of the calyx wall, in the same manner as those of the regular interbrachial areas. The posterior basal is flush with the other plates, and does not differ from the other basals except in being angular or truncate above, and in supporting other plates which are in sutural connection with it.

In *Taxocrinus* the posterior basal is entirely different. It supports no plates at all in direct succession from its distal face, but at a point on the outer surface considerably below the distal margin there is a shallow median depression, or socket, in which rests the first of a series of elongate pieces, curved like arm-plates, forming the support of an anal tube (Pls. XXI, figs. 4, 5; LVII, fig. 5). When all the plates are in position we do not see the entire dorsal side of the posterior basal in its upper half, but only such narrow portions of that part of it as are exposed at either side of the tube, usually more to the left than to the right (Pl. LVII, figs. 4, 5, 6*a*). This tube is attached to the perisome, which forms its inner wall, and it is connected with adjacent brachials by the perisomic integument of pliant skin paved with small irregular plates or spicules. The tube plates are not suturally connected with adjacent plates. Above the tube socket the posterior basal is thinner than below, and its distal face becomes a rather thin and rounded edge, without any surface for sutural union. Thus the lateral faces of the brachials bordering the anal area, instead of being angular and having planes for sutural attachment, are curved from the outside inward to the ventral margins where the perisome is attached; and these margins follow a straight line longitudinally, while the margins facing the other interbrachial areas are zig-zag for their sutural union with the corresponding angular interbrachials. Hence the two can be instantly distinguished if the lateral margin of the ray bordering the anal area can be seen.

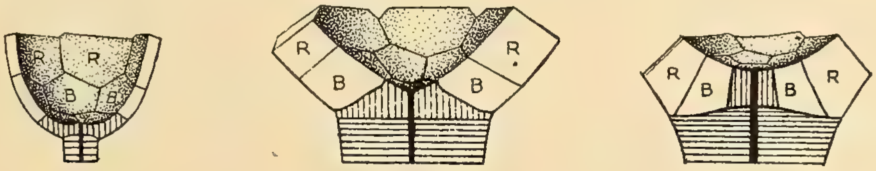
These two structures prevail to a greater or less degree throughout their respective groups. If we could see the exact details of all the specimens we should probably always have a sure criterion in the condition of the posterior basal. If its distal end is suturally united to a succeeding plate, then the form possessing it does not belong to group B, because the tube does not originate there but at least one plate higher up. When the tube originates on the posterior basal it rests in a rounded socket, either at the top or at some distance below the top; and in this case the upper part of the plate thins out to an edge for attachment of the perisome forming the ventral wall of the tube. This structure is perfectly shown by carefully prepared specimens of *Taxocrinus*, *Parichthyocrinus* and *Onychocrinus,* on Plates LVII, LXI, and LXVII, and the external appearance indicates that it is the same, perhaps to a less degree, in *Eutaxocrinus, Gnorimocrinus* and *Protaxocrinus;* even where the tube-socket might seem to rest on the very top of the plate its inner edge would still be non-sutural and smooth for the attachment of perisome. I supposed this to be the case in *Synerocrinus* until I obtained my fine preparation exposing the sutural distal margin of the posterior basal, and a similar sutural attachment for part of the adjoining radial and brachial at both sides (Pl. XLII, figs. 8*a, n*), which shows that the tube begins on the next plate above the basal. This test is decisive for species like *Taxocrinus giddingei* and *T. ungula,* in which the perisome is closely beset with rather strong plates, and it might be thought that the posterior basal is followed by two or more plates abreast. But careful examination will in all cases show that the first plate of the tube rests in a rounded socket on the posterior basal, with a distinct shoulder running up at one or both sides of it; and also that these large plates lack definite arrangement, and are therefore strictly perisomic, whatever their size.

Both these groups passed through the regular successive stages of anal development from that of a radianal in primitive position in form of an inferradial, through a lower to an upper oblique position, and in group A to that of a final complete elimination; these changes correspond with the geological sequence of the genera.

Group B was the earlier in time, so far as is at present known, being found in the Ordovician along with certain Inadunata which clearly mark the line of derivation of the Flexibilia from that order. It continued to the close of the Lower Carboniferous, where it culminated with vigorous species of *Taxocrinus* and *Onychocrinus* in the later Kaskaskia. The group is a strictly homogeneous assemblage of genera, and does not offer any tangible ground for subdivision, except possibly that based upon the dichotomous and heterotomous arm structure; this I do not believe to be a valid character for the differentiation of families, as we have both forms in nearly every family of the Camerata, and in some of the Inadunata and Articulata. The infrabasals are in about the same condition throughout, being low, taking little part in the formation of the calyx wall; but they are not, except in rare cases, so completely buried under the column as is frequent in the other group. This group, therefore, will constitute a suborder with a single family, Taxocrinidae.

Group A arose later, its first known occurrence being in the Silurian; and it culminated in the Warsaw formation of the Lower Carboniferous with *Forbesiocrinus,* a genus which in its later stages emphasizes in the strongest manner the dominant characters of the group. It continued through the equivalent of the Kaskaskia into the Lower Coal Measures, where it has a characteristic representative in *Amphicrinus;* in this, however, there is exhibited a tendency to reversion to the structure of the weak anal side.

This group may be subdivided into three families, the first two of which are more sharply differentiated from the third than they are from each other. The character upon which the principal distinction is based is found in the condition of the infrabasals, and its importance may be made clear by reference to the growth of the calyx plates in the young comatulids. Leaving out of consideration the infrabasals in the latter as usually too rudimentary for comparison, the calyx cup in the early stages consists of basals and radials, both of which form an important part of its wall; the basals are erect, and help to enclose the visceral mass. This is well illustrated in the young *Antedon* as worked out by W. B. Carpenter, and in the larval *Comactinia* herein shown on Plates B and C. The basals at first are not very far from parallel with the dorso-ventral axis of the animal. At a later stage the basals undergo considerable diminution in their external size, and become more and more recumbent in position until they have slipped inward under the central part of the dorsal cup, disappearing from sight altogether; at this stage they cease to take any essential part in the structure of the calyx wall, and in some cases lose their identity by fusing to form the so-called rosette. Primitively the infrabasals underwent a similar transformation, and in the comatulids have been quite lost. This is more fully explained by Mr. Austin H. Clark (Proc. U. S. National Museum, vol. 38, pp. 117, 118), from whose language I have borrowed freely; and he finds that among the Recent crinoids the best characters for the differentiation of the higher groups are found in the stem and in the proportionate recumbency of the basals.



9 10 11

Figs. 9-11

MODIFICATIONS OF INFRABASALS

9. *Lecanocrinus;* IBB more or less erect, forming a definite part of the calyx wall. 10. *Forbesiocrinus;* IBB recumbent, almost withdrawn from the exterior. 11. *Ichthyocrinus;* IBB horizontal, reduced to a small plug, entirely covered by the column.

Examination of the genera belonging to group A shows that they fall into three subdivisions based upon corresponding conditions of the infrabasals:

A*a*. If we take the calyx of *Lecanocrinus* as shown by the cross-section (text-fig. 9) it will be seen that it represents the primitive stage of crinoid growth, in which all the plates occupy their original position forming essential parts of the calyx wall; the infrabasals and basals, therefore, are more or less erect and help to enclose the visceral cavity.

A*b*. In *Forbesiocrinus* (text-fig. 10) the basals have become more oblique, and the infrabasals, now recumbent, have decreased in proportional size so that they form only a small part of the calyx wall, being chiefly a support for the overlying plates.

These two sections range from the Silurian to the Lower Carboniferous, culminating with *Forbesiocrinus* in the Warsaw.

A*c*. In *Ichthyocrinus* (text-fig. 11) the basals approach very nearly the horizontal, while the infrabasals have entirely withdrawn from the exterior, taking no part whatever in the calyx wall.

If we consider infrabasals instead of basals, it will be seen that section A*a* is comparable among Recent forms to *Ptilocrinus* and allied genera; A*b* to the Pentacrinidae; A*c* to the Comatulids; and these would make three well-balanced families if the distribution of the several phases of this character among them were well proportioned and constant. In fact, however, while there is a very sharp distinction among the genera between section *c* on the one hand and *a* plus *b* on the other, this is not the case as between the last two, although the typical examples of them are well differentiated; they shade into one another to a considerable extent, and their separation, which is very desirable from a taxonomic point of view, must be reinforced as far as possible by other characters. These sections, therefore, will form the three families of this group, viz.: A*a*, Lecanocrinidae; A*b*, Sagenocrinidae; A*c*, Ichthyocrinidae.

The Lecanocrinidae, representing the most primitive stage of infrabasal development, in which those plates are more or less erect, are also characterized generally by a rather short, rotund crown. The Sagenocrinidae, in the typical forms of which (*e. g., Forbesiocrinus* rather than the genus from which the name is taken) the infrabasals have become to a large extent recumbent and take little part in the cup enclosing the visceral mass, have usually an elongate, spreading crown. Certain genera like *Cholocrinus* and *Clidochirus* cannot be very satisfactorily placed on account of the intermingling of characters. As between these two sections and the Ichthyocrinidae there is not much overlapping in the condition of the infrabasals. Occasionally in section *b* these plates may not quite appear at the exterior, and thus would not be visible if the column were attached; but in such cases it will be found that there is at the lower part of the plates a flange-like projection by which they extend outward beyond the proximal pentagonal space within the ring of basals (Pls. XXVI, figs. 2*a, b;* XXVIII, fig. 19; XXXI, figs. 4*a, b;* XLIII, fig. 10). This is well shown by many examples, especially in *Forbesiocrinus* where the infrabasals are often pulled off and remain attached to the stem, which have given rise to the idea of a persistent fusion of the infrabasals with the top columnal; this has proved to be not universal in the Flexibilia, and where it exists the sounder view seems to be that it represents merely one retrogressive stage pointing toward the atrophy or disappearance of the infrabasals. Only in *Clidochirus* are the characters offered by the infrabasals thoroughly unreliable.

Within the Ichthyocrinidae the character of reduced infrabasals brings together a number of genera which have always seemed to be related by a certain marked similarity of habitus, yet which differed so much in details such as the presence or absence of interbrachials or of a radianal, and in the mode of arm branching, that I was for a long time unable to frame a diagnosis that would satisfactorily hold them together. The common character producing this similarity of habitus lies in the shape of the rays, which continue more or less to expand from the radials up, the successive brachial series tending to widen distally, so that each ray, taken from the lower angle of the radials to the level of greatest expansion of the crown, is regularly fan-shaped. Thus the increase in diameter of the calyx is accomplished by the brachials themselves, often without the interposition of interbrachial plates. In marked contrast to such forms as *Lecanocrinus, Pycnosaccus,* etc., the radials are not the largest plates in the ray. It was only after I had succeeded in ascertaining the actual structure of the infrabasals in *Dactylocrinus, Wachsmuthicrinus,* and *Synerocrinus,* that the importance of this associated character became apparent. The infrabasal structure is also correlated with a more or less concave base, which is found in most of the genera, the infrabasal elements being completely buried under the column, so that they no longer come in contact with the surrounding water, or contribute essentially to the protection or enclosure of the soft parts; therefore they tend to become atrophied from disuse (see an extreme example of this on Pl. XLI, fig. 5*d*). Aside from the changes due to atrophy, there is but little variation in the shape and position of the infrabasals among eight of the genera composing the family. As a rule they occupy a narrow space surrounding the axial canal, and lie perfectly flat, with their distal faces practically vertical. In *Wachsmuthicrinus* there seems to be a slight tendency to form a thin flange extending outward from the lower part, but rarely reaching the outside (Pl. XLIII, fig. 10); and *Clidochirus,* as already stated, is irregular.

This family represents a homogeneous group, which began in the Silurian and continued through the Devonian into the Lower Carboniferous, running a course substantially parallel to that of the other families, with consistent development of radianal and anal and modification in arm branching, just as we find in those families as well as in the dominant families of the Camerata.

The Ichthyocrinidae, with their infrabasals horizontal, withdrawn from active participation in the formation of the calyx wall, and reduced to a mere vertical plug entirely within and in nowise underlying the basals, represent the nearest approach to a monocyclic condition that is found among the Flexibilia. Having no connection with the exterior, and having lost their original function as part of a cup enclosing the viscera, these plates are in an unstable condition and exhibit a tendency to atrophy; and we therefore find in certain genera an actual resorption of the infrabasals to a greater or less degree, extending in some cases to complete disappearance. In *Euryocrinus* they are partly and in *Cleistocrinus* wholly resorbed. In *Amphicrinus* the infrabasals are found both partially and wholly resorbed in specimens of the same species (see Pl. XL, figs. 9*b*, 10). In at least two species of *Ichthyocrinus* the infrabasals are persistently resorbed, the space which they should have occupied being sometimes left open and well defined (Pl. XXXV, figs. 2*b*, 4*b*, 5). These instances are comparable to the case of the Pentacrinidae, in which family infrabasals are present in the genera *Pentacrinus, Metacrinus, Comastrocrinus, Isocrinus* and *Hypalocrinus,* but always absent in *Endoxocrinus.*

## *The Families of the Flexibilia*

A. Posterior interradius either not differentiated, or containing anal plates not usually formed into a tube, the first of which is incorporated in the calyx by sutural union with adjacent brachials for at least part of its height on both sides. Posterior basal, if differentiated, truncate or angular, and suturally connected with succeeding anal plate.
Suborder........SAGENOCRINOIDEA.

*a.* Infrabasals more or less erect, forming an essential part of the calyx wall. Crown usually short, rotund..................LECANOCRINIDAE.

*b.* Infrabasals more or less recumbent, taking little part in the calyx wall. Crown usually elongate.......................SAGENOCRINIDAE.

*c.* Infrabasals horizontal, not appearing exteriorly and taking no part in the calyx wall. Crown elongate or rotund. Rays widening upward to accommodate expansion of the calyx...ICHTHYOCRINIDAE.

B. Posterior interradius always differentiated and occupied by anal plates in a tube-like series, none of which are suturally incorporated in the calyx. Posterior basal rounded or indented distally and not suturally connected with succeeding anal plate. Crown elongate.
Suborder...........TAXOCRINOIDEA.
A single family........TAXOCRINIDAE.

## *List of the Genera*

### Suborder SAGENOCRINOIDEA

#### Family I. Lecanocrinidae

1. *Lecanocrinus* Hall.
2. *Homalocrinus* Angelin.
3. *Calpiocrinus* Angelin.
4. *Anisocrinus* Angelin.
5. *Hormocrinus* n. g.
6. *Cholocrinus* Springer.
7. *Asaphocrinus* n. g.
8. *Pycnosaccus* Angelin.
9. *Mespilocrinus* de Koninck and Le Hon.
10. *Nipterocrinus* Wachsmuth.

#### Family II. Sagenocrinidae

11. *Temnocrinus* Springer.
12. *Meristocrinus* Springer.
13. *Sagenocrinus* Austin.
14. *Lithocrinus* Wachsmuth and Springer.
15. *Forbesiocrinus* de Koninck and Le Hon.

#### Family III. Ichthyocrinidae

16. *Ichthyocrinus* Conrad.
17. *Cleistocrinus* n. g.
18. *Clidochirus* Angelin.
19. *Synaptocrinus* n. g.
20. *Dactylocrinus* Quenstedt.
21. *Euryocrinus* Phillips.
22. *Metichthyocrinus* Springer.
23. *Wachsmuthicrinus* Springer.
24. *Synerocrinus* Jaekel.
25. *Amphicrinus* Springer.

### Suborder TAXOCRINOIDEA

#### Family IV. Taxocrinidae

26. *Protaxocrinus* Springer.
27. *Gnorimocrinus* Wachsmuth and Springer.
28. *Eutaxocrinus* Springer.
29. *Taxocrinus* Phillips.
30. *Parichthyocrinus* Springer.
31. *Onychocrinus* Lyon and Casseday.

### INSERTAE SEDIS

*Cleiocrinus* Billings.
*Caleidocrinus* Waagen and Jahn
*Edriocrinus* Hall.
*Rhopalocrinus* Wachsmuth and Springer.
*Cydonocrinus* Bather.
*Sycocrinus* Austin.

### Arrangement of Genera and Species

In the text of the systematic part which follows, the genera are treated in the order of their geological succession as they appear in the tables of distribution, which is not always the same as in the analyses of the genera; and the species for the most part are similarly arranged.

## Suborder SAGENOCRINOIDEA

### Family LECANOCRINIDAE Springer

Sagenocrinoidea with infrabasals more or less erect, forming an essential part of the calyx wall. Crown usually short, rotund.

**Analysis of the Genera**

- I. *Rays in contact except at anal side.*
  - Arms dichotomous.
    - RA rhombic, obliquely to lower left of r. post. R.
      - Anal *x* alone.
        - Arms interlocking. IBr 2 (exceptionally 1)................Lecanocrinus.
    - No RA.
      - Anal *x* alone, or followed by small triangular plate.
        - Arms not interlocking, usually rounded, with dextrorse twist. IBr 2....................Mespilocrinus.
- II. *Rays above radials partly separated by solid plates arched over by brachials.*
  - Arms heterotomous. IBr 2.
    - Base highly specialized. IBB enveloping BB.
      - Anal *x* and large iBr followed by others.
    - RA under r. post. R, between BB.
      - 10 main rami, with ramules..............................Homalocrinus.
    - No RA.
      - 20 main rami, with ramules................................Calpiocrinus.
  - Arms usually dichotomous. IBB of usual form. IBr 2.
    - RA irregularly under r. post. R, above line of BB (exceptionally oblique, or wanting).
      - Anal *x* and iBr 1 large alone, or followed by others.............Anisocrinus.
- III. *Rays above radials separated by solid plates followed by perisome.*
  - Arms dichotomous. No RA. IBr 2.
    - Anal *x* and large iBr followed by others abreast and perisome, or directly by perisome...............................Hormocrinus.
- IV. *Rays above radials separated by perisome only.*
  - Arms heterotomous. IBr 2.
    - RA rhombic, obliquely to lower left of r. post. R.
      - Anal *x* followed by perisome. No iBr.
        - 10 main rami with irregularly branching ramules.............Cholocrinus.
  - Arms dichotomous.
    - RA rhombic, obliquely to lower left of r. post. R.
      - Anal *x* followed by others passing into a tube.
        - No iBr, areas filled with perisome, sometimes not exposed.
          - IBr 2 ..............................................Asaphocrinus.
      - Anal *x* alone, followed by perisome.
        - No iBr, areas wide filled with perisome. IBr 1 to 4...........Pycnosaccus.
    - No RA, anal plate, or iBr.
      - iBr areas wide, filled with perisome. IBr 2 to 4...............Nipterocrinus.

This family embraces an assemblage of genera most strongly contrasted with the Ichthyocrinidae in the condition of the infrabasals, which are erect, helping to enclose the visceral cavity. This is typified in the genus *Lecanocrinus,* where they form an upright cup resting upon the column. In two of the genera, *Homalocrinus* and *Calpiocrinus,* the prominence of the infrabasals is exaggerated to a high degree of specialization, overshadowing all the other basal structures. This modification was short-lived, and was not repeated elsewhere among the Paleozoic crinoids. Correlated with the above-mentioned infrabasal character in the family is the small, short and subglobose habitus of the crown. The arms are usually short, or appear so by being closely folded over the tegmen, producing a more or less compact, ovoid body. This character is quite constant throughout the genera, *Cholocrinus* alone showing a marked departure from it. *Asaphocrinus* has a somewhat less globose form than most of the others, and also exhibits a tendency toward the anal structure of the Taxocrinidae. The only genera of the other families which are liable to be confounded with those of this family by reason of similarity in general form and habitus, and the infolding of the arms, are usually larger and are readily distinguished by their other characters. Various stages of anal structure are progressively exhibited in this family, from those of radianal in primitive position, oblique, or anal *x* without radianal in the Silurian, to complete elimination of both radianal and anal plates in the Carboniferous.

The family is essentially Silurian, eight of its ten genera belonging to that age, only two of which, *Lecanocrinus* and *Pycnosaccus,* are feebly represented in the Devonian. The two Carboniferous genera, *Mespilocrinus* and *Nipterocrinus,* which are morphologically the direct successors respectively of *Lecanocrinus* and *Pycnosaccus,* are confined to the lower part of the Lower Carboniferous, and the family, so far as known, became extinct at the close of the Burlington limestone. Five of the genera, *Lecanocrinus, Mespilocrinus, Anisocrinus, Hormocrinus* and *Pycnosaccus,* are common to both Europe and America. *Homalocrinus* and *Calpiocrinus* are confined to England and Gotland, while *Asaphocrinus* and *Nipterocrinus* have not been found outside of America.

### *Geological and Geographical Distribution*

**Number of known species**

(Open figures indicate American, those marked ( ) European)

| FORMATION | | | LECANOCRINIDAE | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| General | American | Approximate European Equivalents | Lecanocrinus | Homalocrinus | Calpiocrinus | Anisocrinus | Hormocrinus | Cholocrinus | Asaphocrinus | Pycnosaccus | Mespilocrinus | Nipterocrinus | Total |
| L. Carboniferous | Upper Burlington.......... | .......... | ... | ... | ... | ... | ... | ... | ... | ... | 1 | 1 | |
| | Lower Burlington .......... | Mountain limestone | ... | ... | ... | ... | ... | ... | ... | ... | 3<br>(1) | 1 | |
| | Kinderhook-Waverly....... | | ... | ... | ... | ... | ... | ... | ... | ... | 2 | ... | 9 |
| Devonian | ......................... | Upper | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | |
| | Hamilton ................. | Middle | ...<br>(1) | ... | ... | ... | ... | ... | ... | 1 | ... | ... | |
| | Helderbergian............. | Lower | 1<br>(1) | ... | ... | ... | ... | ... | ... | 1 | ... | ... | 5 |
| Silurian | Niagaran.................. | Wenlock | 6<br>(5) | ...<br>(3) | ...<br>(5) | 2<br>(3) | 1<br>(2) | ...<br>(1) | 4 | 5<br>(3) | ... | ... | 40 |
| | American species .......... | 29 | 7 | ... | ... | 2 | 1 | ... | 4 | 7 | 6 | 2 | |
| | European species .......... | (25) | (7) | (3) | (5) | (3) | (2) | (1) | ... | (3) | (1) | ... | |
| | Total species .......... | 54 | 14 | 3 | 5 | 5 | 3 | 1 | 4 | 10 | 7 | 2 | 54 |

## **LECANOCRINUS** Hall

*Plates I-III*

*Lecanocrinus* Hall, Nat. Hist. New York, Pal. II, 1852, p. 199.—Pictet, Traité Palaeontologie, IV, 1857, p. 319.—Bronn, Klassen u. Ord. Thier-Reichs, II, 1860, p. 231.—Schultze, Mon. Echinodermen Eifler Kalkes, 1867, p. 40.—Beyrich, Monatsber. Akad. Wiss. Berlin, 1871, p. 42 (Transl. in Ann. and Mag. Nat. Hist., (4) VII, p. 403.—Quenstedt, Petref. Deutschlands, IV, 1876, p. 516.—Angelin, Icon. Crin. Sueciae, 1878, p. 11.—Von Zittel, Handbuch Palaeontologie, 1879, pp. 343, 355; Grundzüge Palaeontologie, 1895, p. 138.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 39; Proc. Acad. Nat. Sci. Philadelphia, 1890, p. 388.—Oehlert, Bull. Soc. Geol. France (3) X, 1882, p. 354.—Miller, N. A. Geology and Palaeontology, 1889, p. 257.—Zittel-Eastman, Text-book Palaeontology, 1896, p. 163 (2d Ed. 1913, p. 203).—Bather, Rep. British Assoc. for 1898 [1899], p. 923; Treatise on Zoology (Lankester), pt. 3, 1900, p. 188.—Weller, Bull. 4, Chicago Acad. Sci., VII, 1900, p. 147.—Springer, Amer. Geologist, XXX, 1902, p. 94; Jour. Geology, XIV, 1906, pp. 491-501.

*Cyrtidocrinus* Angelin, Icon. Crin. Sueciae, 1878, p. 20.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 3, 1886, p. 144.

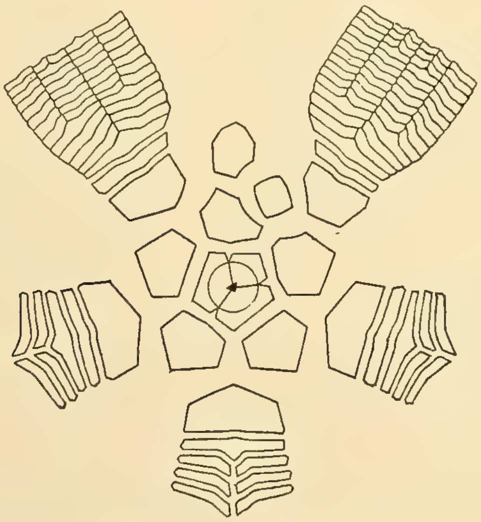


Fig. 12. *Lecanocrinus*

Lecanocrinidae with rays in contact except at anal side. Crown short and ovoid, main expansion in zone of radials; calyx well differentiated. Infrabasals usually more or less erect forming part of the calyx wall. Radianal rhombic, obliquely to lower left of right posterior radial, resting on basals, not touching right anterior radial. Anal *x* alone, filling posterior interradius; no interbrachials in other areas. Primibrachs two, exceptionally one. Arms dichotomous, interlocking. Column not enlarging proximally, or but little; columnals usually alternating from the top, becoming uniform farther down.

*Genotype. Lecanocrinus macropetalus* Hall.

*Distribution.* Silurian and Devonian; Continental Europe, England, and North America.

*Lecanocrinus* is the type of its family, having usually a short, ovoid crown, with base well developed, both infrabasals and basals more or less erect forming an important part of the calyx wall. The chief expansion is in the proximal region of the crown, producing the form of a calyx composed of prominent basal and radial plates, and well differentiated from the succeeding structures. In this respect it is in marked contrast with *Ichthyocrinus* and its allies, in which the base and the radials are an immaterial part of the crown, whose expansion is chiefly above their level. Therefore there is not the wedge-like widening of the rays from an insignificant radial to larger and increasingly wide primibrachs so characteristic of *Ichthyocrinus;* but their form is fixed by the width of the radials, to which they substantially conform except in the posterior rays, where there is some widening of the brachials to form an arch over the anal plate. Hence in a typical species the sides of the rays are approximately parallel; but there are species somewhat intermediate in this respect in which the radials are diminished and the primibrachs increase. The genus is remarkable for the occasional occurrence of only one primibrach. The usual number is two, and there are few exceptions to this in the Silurian species; but in Schultze's *L. roemeri,* from the Devonian, it varies with the individual, one being more frequent than two. Secundibrachs vary from three to four, some specimens of *L. macropetalus* having three in all rays, some four in all, while others have both numbers with varying degrees of preponderance. Tertibrachs, which are rarely seen in full except in the last-named species, vary from six to nine, with another bifurcation above.

In the condition of the radianal this genus is not so primitive as genera like *Ichthyocrinus,* in which that plate is in the position of the lower half of a compound radial, or the inferradial; here it is oblique, resting upon the right shoulder of the posterior basal, and therefore, not being in contact with the right anterior radial, its outline is necessarily quadrangular (frequently with slight curvature at the sides) instead of pentangular as in those cases. In this condition it passes from the Silurian into the Devonian, where the radianal is somewhat reduced in size; and it is succeeded in the Carboniferous by *Mespilocrinus,* in which the radianal has entirely disappeared.

The infrabasals typically are large and well-developed plates, standing erect and forming a part of the calyx wall;[1] in some species they are less prominent, but in none except *Lecanocrinus meniscus* are they such insignificant plates hidden under the column as in *Ichthyocrinus.* The three Devonian species show a departure from the family type of large infrabasals, but in that horizon we may always expect to find variation and uncertainty of characters in preexisting genera. The basals are very large, often forming half the calyx up to the radial facets; the posterior basal, by reason of its contact with the anal and radianal plates, is of a very different shape from the others, its geometrical figure necessarily resulting from these connections; it is not larger than the others, and does not rise to such a great height as in *Mespilocrinus.* The anal plate, truncating the posterior basal and forming one boundary of the radianal, is very large, often rising to the height of the first secundibrach; it completely fills the interradius, and suturally connects by definite sides and angles with the plates of adjacent rays, which arch over it, and abut in line above its apex. The arcuate sutures are not usually so prominent in this genus, being scarcely ever seen on the radials. The calyx of *Lecanocrinus* is much more strongly constructed than that of *Ichthyocrinus;* its walls in the lower part are thicker, and the base less liable to distortion.

There is also a very distinct difference in the column from *Ichthyocrinus.* Instead of having a turbinate enlargement of equally thin plates at the proximal end enveloping the infrabasals and sometimes a portion of the succeeding plates (Pl. XXXIII), it is here cylindrical, of much less diameter than the infrabasal ring; and the proximal columnals in some cases begin at once to alternate in length, gradually increasing until the internodals disappear, and the ossicles become uniformly longer and rounded on the sides. In some species there is no visible alternation of short columnals, and in some the contrast is carried to an extreme.

This genus has been confused with *Anisocrinus* by Angelin, who figured under it a specimen of that genus, and it was classed by him in the family Homalocrinidae, along with

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[1] Text-fig. 9, p. 117.

*Homalocrinus, Calpiocrinus,* and *Anisocrinus;* but it is broadly separated from all these by the absence of interbrachial structures.

Hall's generic diagnosis of *Lecanocrinus*[1] contained chiefly what we now regard as family characters, but he noted the presence of an "interscapular" (anal) plate. With his usual strong grasp of fundamental relationships in fossils, even at that early day when these matters were by no means understood as they are now, he was struck by what he called "a very interesting analogy" between this form and *Ichthyocrinus.* He showed how, if the "three minute plates" at the base of the latter should be more fully developed, "we should have the pelvis of *Lecanocrinus"*; and a like development of the five "triangular pelvic plates" of *Ichthyocrinus* would produce the "costal plates of *Lecanocrinus.*" And he proceeded to show a still further analogy between the two genera by reference to a diagram (*op. cit.,* pl. 45, fig. 2) showing a small intercalated plate, which he compared to the "intercostal plate" (radianal) which he had described in *Lecanocrinus.* This diagram, however, simply shows an exceptional case, of which I have seen two or three, where an accidental interbrachial plate appears; it has no place in the structure of *Ichthyocrinus.*

Schultze[2] discussed the genus in connection with his species from the Devonian, and proposed to extend its geological range by including the two species described by De Koninck under *Mespilocrinus,* which he declared "undoubtedly belong to *Lecanocrinus.*" The importance of the radianal as distinguishing these two genera had not then been recognized, but Schultze did not overlook the plate, which he called a second smaller interradial, saying that, "according as it is more or less developed is to be reckoned either with the radial or parabasal ring."

Bather[3] correctly diagnosed the genus, and placed it in a family with *Ichthyocrinus, Clidochirus, Mespilocrinus, Pycnosaccus* and *Nipterocrinus,* which in regard to the last three agrees with the present arrangement.

Angelin's *Cyrtidocrinus,*[4] said by him to have four "basalia" (*i. e.,* infrabasals), and for that reason referred to a different family, is a synonym of this genus. It was founded upon incorrect observation, as Liljevall's figures of the principal specimens show (Pl. II, figs. 16-20).

Billings[5] referred to this genus two species which made confusion for a time, as they possess scarcely any of its characters, but belong to the Taxocrinidae.

Although *Lecanocrinus* is thus very satisfactorily defined generically, the discrimination of its species is often very difficult and unsatisfactory. It is a simple form, with not many points of variation to furnish diagnostic characters, and many of the specimens are small. No less than 14 species have been described under this genus or are referable to it, and as to over half of them no assistance whatever can be had from the author's descriptions to show wherein they differ from others. Hence criteria for separation must be independently sought. In general form we have the difference between a concave and convex base; nearly all the species fall under the latter category, and under it there seems to be every gradation in form of calyx from elongate to depressed, and from conical to globose. Surface characters count for something, and beyond this we must rely on the form and relative dimensions of the anal plate, size of basals, radials and primibrachs, the protuberance of the base, and the character of the column facet.

The geological range of *Lecanocrinus* is considerable, beginning with the type species in the Rochester shale, and extending through the Laurel, Waldron, Brownsport, Racine, and Louisville of the Silurian to the Middle Devonian. It is represented in America by seven described species and by a like number in Britain and continental Europe at corresponding Silurian and Devonian horizons.

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[1] Nat. Hist. New York, Paleontology, vol. 2, p. 199.

[2] Monograph Echinodermen des Eiflerkalkes, 1867, p. 40.

[3] Lankester's Treatise on Zoology, pt. 3, p. 188.

[4] Iconog. Crin. Suec., 1878, p. 20.

[5] Canadian Organic Remains, Decade 4, 1859, p. 47.

I take the chief comparative measurement of general dimensions in this genus at the apex of the axillary primibrach, as in some species the arms infold before the next bifurcation, and in many specimens they are not preserved. All measurements are in millimetres. To facilitate comparison, I have arranged the Silurian and the Devonian species in separate groups.

### The Species of Lecanocrinus

#### *Silurian Species*

I. IBB protuberant.
Surface smooth.
RR large. Anal *x* large, and rising high above radials.
BB large. Crown ovoid.................................*L. macropetalus.*
Crown pyriform.................................*L. solidus.*
Surface ornamented, calyx plates thick.
RR large. Anal *x* short and wide, crown subglobose.................*L. pusillus.*
RR small. Anal *x* long and narrow, crown ovoid..................*L. billingsi.*
II. IBB not protuberant.
Base not concave.
RR large, IBr short. Anal *x* not projecting high.
Anal *x* truncate. IBB visible in side view.
Surface fine pitted network.
Calyx walls thin.......................................*L. facietatus.*
Surface coarse granules. RR smaller.
Calyx walls thick.......................................*L. lindstromi.*
Anal *x* acuminate. IBB not visible in side view.
Calyx walls thin.......................................*L. pisiformis.*
RR small. IBr long, increasing in width upward.
IBB visible. Base rounded...................................*L. bacchus.*
Base truncate. Br angular........................*L. angulatus.*
IBB invisible. Base truncate, involving part of BB..............*L. meniscus.*
Base concave.
BB large. RR small.
IBB large, radiating ridges on plates.........................*L. waukoma.*

#### *Devonian Species*

IBB not protuberant.
Base excavate. Anal *x* not projecting.
Calyx pentangular...............................................*L. roemeri.*
Base truncate, calyx circular.
Anal *x* little projecting, surface coarsely granular....................*L. soyei.*
Anal *x* projecting over half above RR.....................*L. magnaradialis*

### **Lecanocrinus macropetalus** Hall

*Plate III, figs. 1-18*

*Cyathocrinus* ? Hall, Geol. Fourth District New York, 1843, Tables Organic Remains, No. 21, figs. 5, 5*a*, 5*b*.

*Lecanocrinus macropetalus* Hall, Nat. Hist. New York Pal. II, 1852, p. 199, pl. 45, figs. 1*a-h*.—Bronn, Klassen Ord. Thier-Reichs, pl. 27, figs. 6*a-d*.—Beyrich, Monatsber. Acad. Wiss. Berlin, Feb., 1871, p. 46 (Transl. in Ann. and Mag. Nat. Hist. (4) VII, p. 404).—Quenstedt, Petref. Deutschlands, IV, 1876, p. 516, pl. 108, fig. 26.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 40; Proc. Acad. Nat. Sci., Philadelphia, 1888, p. 357.—Miller, N. A. Geology and Palaeontology, 1889, p. 257, fig. 348.—Grabau, Bull. 45, N. Y. State Mus., IX, 1901, p. 160, fig. 55.—Springer, Jour. Geology, XIV, 1906, pl. 6, figs. 13, 14.

*Lecanocrinus puteolus* Ringueberg, Bull. Buffalo Soc. Nat. Sci., V, 1886, p. 11, pl. 1, fig. 8.

Not *Lecanocrinus macropetalus*, Angelin, Icon. Crin. Sueciae, 1878, p. 12, pl. 19, figs. 3, 4; pl. 22, fig. 24 = *Anisocrinus angelini* W. and Sp.

Type of the genus.

A large species, variable in size. Crown elongate ovoid, evenly curved and without angularity; base rounded, sometimes protuberant; average height to width at IAx, about 1 to 1.1; at $IIBr_4$, 1.1 to 1; at distal face of RR, 1 to 1.6. Surface smooth; calyx plates thin. Maximum crown, 30 mm. high by 20 mm. wide at $IIBr_4$; column facet, 5 mm.

IBB large, protuberant. BB large. Anal *x* very large, often reaching to IIBr, projecting at least half its height above level of radials. RR large, three times the height of IBr. Relative height in millimeters of B to R to IBr, 8:6:1.5. IBr 2; IIBr 3 or 4; either in all the rays, or varying in different rays of the same specimen; IIIBr 6 to 10 or more, the greater number in the outer ramus. Rays interlocking to IIBr, closely abutting and infolding above; not increasing in width upward. Arms flush with the general curvature, without angularity or marked convexity; diminishing rapidly in width from IIBr up. Column facet concave, shallow, not indented. Column with decided alternation of long and short columnals next to the calyx, the longer ones rounded, gradually becoming uniform; the contrast between long and short ossicles is greater in young specimens.

I usually omit from the diagnosis of this and following species characters which are merely generic, common to all the species of the genus; or which necessarily result from its essential structure, such as the presence, absence, or position of radianal plates, or the number of primibrachs, except when the character is subject to variation within the genus; also characters which are fundamental for the entire group, such as the number of infrabasals, basals, and radials. Such repetition not only serves no good purpose toward specific definition, but is pedantic and wearisome, too often put into specific descriptions for the purpose of "padding," to conceal the insufficiency of real specific characters, or the indisposition of the author to take the trouble of ascertaining or clearly stating what they are.

It is fortunate that this, the typical species of the genus, is fairly abundant at the original locality, Lockport, New York and in the same shales at Grimsby, Canada. The word "abundant" is used in a relative sense, for the sum total of Dr. Ringueberg's collecting for over 20 years and of my own subsequently is about 20 specimens, and Sir Edmund Walker's collection from Grimsby contains about the same number. The Hall collection in the American Museum has about a half dozen. By a selection of specimens from these collections, and a few obtained by me from other sources, we are enabled to illustrate the species in great variety as to form and maturity. Most of them are flattened by pressure and give a wrong impression of the true outline. A few, such as figures 17 and 18 on Plate III, are undistorted and show the correct figure, which is an elongate ovoid with the widest part above the upper primibrach, and a relative height to width at that level of about 1 to 1.1. Many measurements and calculated diameters yield about the same general average in form and proportions; and observation of about 40 specimens shows no variation in the normal number of two primibrachs, but variation from three to four among the secundibrachs. The radial is a large plate, of more than the combined height of the three succeeding brachials—a proportion which differs considerably in different specimens.

On comparing the young with the mature specimens a great difference is observed in the development of the arms. In a full-grown specimen (Pl. III, fig. 10) three bifurcations are in view; those of medium size (figs. 17, 18) show but two; while in a very young individual there is but one (figs. 15, 16). This juvenile character in the brachials becomes constant in another species, as will be seen farther on. The axial canal in the column is rounded or obscurely pentangular, but at the inner surface of the infrabasals it enlarges into a triangular opening, bounded by a low rim, with the angles directed to the middle of the infrabasal plates (Pl. III, figs. 6*a*, *b*); this is similar to the structure seen in *Forbesiocrinus* and *Ichthyocrinus.*

I have figured three of Hall's types from the American Museum. His figure 1*a* (Nat. Hist. New York, Pal., vol. 2, pl. 45) is incorrect in the drawing of the arms above the first bifurcation, where it shows only a single secundibrach. The divisions of the higher brachials are not always easily observed in the specimens as found, and these details were not thought so important at that time. Similar errors appear in his figure 1*b,* where the left posterior ray is incorrectly made to show three primibrachs; but in Hall's description the facts are correctly stated.

Ringueberg's *L. puteolus* is probably a calyx of this species injured by parasites. Hall's *Lecanocrinus simplex* (*op. cit.,* 1852, p. 202, pl. 46, figs. 2*a-e*), is doubtless a very young *Ichthyocrinus,* and the figures as to details of base and surface ornament are probably not strictly correct; the specimen cannot be found, but I have figured two similar ones under *Ichthyocrinus laevis.*

*Types.* In the American Museum of Natural History, New York. The original of Plate III, figure 7, is in the University of Toronto; the other specimens figured are in the author's collection.

*Horizon and locality.* Silurian, middle third of the Rochester shale; Lockport, New York, and Grimsby, Canada. It has not been found in the equivalent Osgood formation, nor in the Waldron shales of Indiana and Tennessee.

### **Lecanocrinus solidus** Ringueberg

*Plate III, fig. 19*

*Lecanocrinus solidus* Ringueberg, Bull. Buffalo Soc. Nat. Sci., I, 1886, p. 8, pl. 1, fig. 4.

A large species. Crown elongate, pyriform; height to width at IAx, 1 to 1.1; base narrow, its side outline continuous with the column, and concave for a short distance. Surface smooth. Height of crown, 30 mm., width at $IIBr_4$, 18 mm.; column facet, 5 mm.

IBB protuberant, very large, forming a truncate cone. BB large. Anal *x* high, acute-angular, extending for one-half its height above the radials. RR proportionally small, not over twice the height of IBr; height of B to R to IBr, 6:5:2.5. IBr 2; IIBr 3 in all rays visible; IIIBr 6 to 9. Arms bifurcating again before infolding; rather flat and tapering but little. Column large, as wide as the truncate base; with strong alternation of long and short ossicles beginning at the proximal end and continuing for more than 20 long nodal columnals with short internodals interposed.

This species is represented by a single specimen, no other except Dr. Ringueberg's type having been found; but that is a remarkably fine and perfect one. While its relative dimensions at the upper primibrach are about the same as those of *L. macropetalus,* the outline of the calyx is altogether different, and the proportions of the infrabasals, radials, arms and column give it quite another aspect from that species. It was found in the lowest of the shales at Lockport, therefore below the zone of *L. macropetalus.*

*Type.* Author's collection.

*Horizon and locality.* Silurian, lower third of Rochester shale; Lockport, New York.

## **Lecanocrinus pusillus** (Hall)

*Plate I, figs. 1-13*

*Cyathocrinus pusillus* Hall, Adv. Abstr. Trans. Albany Inst., IV, 1863, p. 6; Final Rep., 1864, p. 200; Prelim. Notice 18th Rep. N. Y. St. Cab. Nat. Hist., 1865, p. 20; 20th Rep., 1868, p. 324; Revised Ed., 1870, p. 366.—Shumard, Trans. Acad. Sci. St. Louis, II, 1866, p. 363.

*Lecanocrinus pusillus* Hall, 28th Rep. N. Y. St. Cab. Nat. Hist. (Doc. Ed.), 1876, expl. of plate 15 (Mus. Ed., 1879, p. 136, pl. 15, figs. 1-6); 11th Rep. Geol. Nat. Hist. Indiana, p. 267, pl. 14, figs. 1-6; pl. 15, fig. 7.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 40.—Weller, Bull. 4, Chicago Acad. Sci., pt. 1, 1900, p. 148, pl. 15.—Foerste, Bull. Geol. Soc. America, XII, 1901, p. 443; Jour. Geology, XI, Oct.-Nov., 1903, pp. 708, 712.

*Lecanocrinus Tennesseensis* S. A. Miller, Adv. sheets 17th Rep. Geol. Surv. Indiana, 1891, p. 41, pl. 7, figs. 7, 8; Final Rep., 1892, p. 651.

A medium-sized species. Crown subglobose, widest at IAx where height to width is 1 to 1.3; average height to width of 15 specimens at top of RR, 1 to 1.65; base rounded. A complete crown is 19 mm. high by 15 mm. wide at top of IAx; maximum calyx, 10 mm. high by 16 mm. wide at RR; width at column facet, 3.5 mm.; minimum calyx, 5 by 9. Calyx walls thick. Surface ornamented with fine raised granules, often coalescing into a wrinkled lace-work.

IBB large, usually following the curvature of adjoining plates; visible in side view, and often protuberant. BB large. Anal *x* short and wide (almost as wide as high), projecting half its length above the radials. RR large, about two and one-half times the height of primibrachs; average height of B to R to IBr, 5:5:1.5. IBr 2; IIBr 3 or 4, with another bifurcation visible. Rays closely abutting, sides about parallel; arms flat, longer than in *L. pisiformis,* and not tapering so rapidly. Column facet shallow, saucer-shaped. Column rather large, composed from the top down of wide and conspicuous rounded nodal columnals, with narrow internodals regularly intercalated.

*Lecanocrinus pusillus* belongs to a more globose type than *L. macropetalus,* and differs in the surface ornamentation. It may be considered as corresponding in a general way to *L. billingsi* of the Gotland rocks, just as *L. pisiformis* does to *L. facietatus.* It has the same thick calyx walls, so that specimens are rarely flattened. As compared with *L. pisiformis* it has a lower and broader calyx, the crown not constricted at the primibrachs, larger infrabasals and basals, and smaller radials. The broad and relatively low obtuse-angled anal plate, shallow column facet, and thick calyx walls are plain and evident characters to distinguish it from the species most likely to be encountered in the same region. There is some variation in the protuberance of the infrabasals, this being quite marked in some specimens. The surface ornament was evidently strong, as it is usually preserved on the specimens. In addition to the enlarged view shown on Plate I, figure 4*c,* the surface markings may be seen with an ordinary magnifier on two of the full figures 4*b* and 10 on the same plate.

The species is a very characteristic fossil of the Niagaran shales at Waldron, Indiana, and Newsom, Tennessee, but has not been found at Lockport, or other New York or Canada localities. It is not so abundant as the species from the Brownsport limestone, and is rarely found with any part of the arms attached. But a single specimen is known with the arms complete, and that is the one figured by Hall in the 11th Indiana Report, plate 15, figure 7, and now in the New York State Museum (Pl. I, figs. 3*a, b*). Another specimen in my collection preserving the rays to $IIBr_1$, also from Waldron, is an unusually elongate form, (fig. 9) but has the characteristic surface ornamentation (not shown in the figure), and is undoubtedly a variant of this species. One of Hall's type specimens (28th Rep., pl. 15, fig. 5) had abnormally a second anal plate which he made a specific character; his other specimen (his fig. 4) shows the usual form of the single plate, which I have found constant in 25 specimens from two localities. One of my specimens has an abnormal base, the proximal ring being composed of three small infrabasals and one large plate which combines the functions of both infrabasal and basal, there being but four of the latter. The column of the perfect specimen is so very unusual for this genus as to be almost abnormal; such extreme contrast in the size of the alternating columnals I have not seen in any other species.

Hall described this species originally under *Cyathocrinus;* but a few years afterwards he saw its relation to his own genus and made the reference accordingly in the 28th Report.

*Types.* The originals of the 28th Report, plate 15, figures 1-6, are in the American Museum of Natural History, New York; that of the 11th Indiana Report, plate 15, figure 7, is in the New York State Museum. The other specimens figured are in the author's collection.

*Horizon and locality.* Silurian, Waldron shales; Waldron, Indiana, and Newsom, Tennessee. Also rarely in the Laurel beds at St. Paul, Indiana.

### **Lecanocrinus billingsi** Angelin

*Plate II, figs. 1-15*

*Lecanocrinus billingsi* Angelin, Icon. Crin. Sueciae, 1878, p. 12, pl. 22, fig. 25*a.*—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 40.

A small species. Similar to *L. pusillus,* but in general the calyx is proportionally lower and broader, the average of several specimens giving height to width at IAx of 1 to 1.4; at top of RR, 1 to 1.8. It is less rounded below, RR shorter, and IBr proportionally longer; height of B to R to IBr, 2.5:2.7:1.2. The arms are proportionally heavier, more rounded, longer and extending higher up before infolding. Column composed of short ossicles, increasing in length but of uniform width, without alternation in either. Surface marked by fine granular network. Maximum crown is 16 mm. total height by 10 mm. wide at IAx; at RR, 5 mm. by 8.5 mm.; width at column facet, 2.5 mm.

This is one of two rather abundant species in Gotland corresponding somewhat to *L. pusillus* and *L. pisiformis* of the American Niagaran. They occur in different localities, the present species being found in the vicinity of Wisby, in horizon *d*, whereas the other is from the south of Gotland. This is of the type of *L. pusillus*, having the same thick calyx walls, and distinct though very fine granular ornamentation; yet there is enough constant difference to preclude its reference to that species. Its average size is nearer that of *L. pusillus*, but it is otherwise not at all like that species; nor does it represent a juvenile type, the arms being heavy and well developed to the third bifurcation. There are 148 specimens in the Riks Museum, of which 14 have more or less of the arms preserved. In these 14 there are 40 complete rays, and with one exception they all have two primibrachs. Among this large number of specimens are some interesting variations in the construction of the calyx parallel to what is shown in our Tennessee species. These variations, shown on Plate II, are chiefly in the development of the plates of the anal side, on which some of our most important generic distinctions are based.

Three of the specimens have an abnormal radianal; one has RA unusually small and triangular instead of quadrangular (fig. 8); one has RA in primitive position below r. post. R, as in *Clidochirus* (fig. 9); while in the third the RA lies vertically below the anal *x* (fig. 10). Nine specimens have no radianal at all (a Silurian *Mespilocrinus*), the space belonging to the missing plate being filled up in different ways; six of them have the posterior basal much enlarged (fig. 11); two have the right posterior basal enlarged (fig. 12); while the remaining one, not figured, is a deformed specimen with only four radials and two basals. In three specimens the large anal *x* is wanting; one having RA normal (fig. 13) is unlike any described genus; a second has RA in primitive position like *Ichthyocrinus* (fig. 14); and the third is hopelessly malformed. In addition to these there is another specimen with normal RA and anal *x* which has only three large radials completing the circlet, and a basal ring of seven plates of varying size and form abutting upon the infrabasals; and besides these a quadrangular plate (a sort of supernumerary RA) between the ring of basals and radials to the right of the r. post. B (Pl. II, figs. 15*a*, *b*).

In sufficiently energetic hands this little collection of abnormal *Lecanocrini*, although from the same area and horizon, might form the basis of a choice assortment of new genera and species, such as have sprung up in some of our rich American localities. Yet it is perfectly evident that they represent merely the variations of a single prolific species, either reproductions of different embryonic or larval stages, or mere sporadic malformations. Figure 3 gives an inside view of the calyx, showing very plainly the triangular enlargement of the axial canal.

*Types.* Angelin's principal figure (Icon. Crin. Suec., pl. 22, fig. 25) is a restoration, but the specimen on which it was based is refigured on Plate II, figure 1. That and all the other specimens figured herein are in the Riks Museum, Stockholm.

*Horizon and locality.* Silurian, Wenlock Group, horizon *d;* Wisby, Island of Gotland, Sweden.

### **Lecanocrinus facietatus** (Angelin)

*Plate II, figs. 16-21*

*Cyrtidocrinus facietatus* Angelin, Icon. Crin. Sueciae, 1878, p. 20, pl. 21, figs. 13-14*a*.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 145.

A small species. Crown subglobose, obtusely rounded or truncate below, widest at top of IAx; average height to width at that level about 1 to 1.1; at top of RR, 1 to 1.3. Surface marked by small pits, producing a very fine network usually not preserved in the specimens. Calyx plates thin. Maximum specimen at IAx, about 10 mm. high by 11 mm. wide; at RR, 8 mm. by 11; width at column facet, 3.5 mm.

IBB not prominent, but visible in side view. BB large. Anal *x* truncate or obtusely angular, scarcely higher than radials. RR very large, four or five times the height of IBr; height of B to R to IBr, 3.5:4.5:1. IBr variable, one or two. Higher brachials and column unknown.

Angelin thought this species had four "basalia" (infrabasals), and therefore proposed for it the genus *Cyrtidocrinus*. This was due to incorrect observation, and his genus cannot be upheld. The type specimen cannot be identified, and his figures show a peculiar surface marking, as if there were depressed strips on the plates running parallel to their margins such as I have seen occasionally in other species (cf. *L. macropetalus*, Pl. III, figs. 8*a*, *b*); but this was evidently much exaggerated by the artist, as it is not shown on any of Mr. Liljevall's drawings.

There are two abundant and well-marked species of *Lecanocrinus* in Gotland. One occurs in the northern region at and near Wisby, in horizon *d*, and it has very thick calyx walls, high, acute-angled anal *x*, and relatively small radials; the other occurs at Nafdem, Hablingbo, and other localities in the south of Gotland in horizon *c* or *d*, and has a thin calyx, low obtuse-angled anal *x*, and very large radials. The first, as we have already seen, is *L. billingsi*. The second is considered at the Riks Museum to be *L. facietatus*, and the form of the anal plate in Angelin's figures indicates the correctness of this reference.

Of this species there are about 120 specimens in the Riks Museum, but very few with any part of the arms attached. There seems to be more irregularity in the number of primibrachs than is usual in Silurian species. Out of 12 specimens of which the IBr are preserved in 26 rays, 15 rays have two IBr, and 11 have only one. The form bears considerable resemblance to *L. pisiformis* from Tennessee, especially in the low anal *x* and very large radials; but it has better developed infrabasals and a more truncate base, and differs in the surface ornament—the latter a poor criterion practically because the surface is rarely well preserved. It is probable that the so-called ornament which I have illustrated on Plate II, figures 19*d*, 21*c*, is nothing more than the network formed by the surface growth of stereom, and that this surface ought to be called smooth.

*Type.* Cannot be identified; the specimens figured herein are all in the Riks Museum, Stockholm.

*Horizon and locality.* Silurian, Wenlock Group, horizons *c* and *d*. Nas, Nafdem and Hablingbo, Gotland.

### **Lecanocrinus lindströmi** n. sp.

*Plate II, figs. 22, 23*

Similar to *L. facietatus* as to the anal plate, but having proportionally stronger IBB, thicker calyx walls, and a different style of surface ornament consisting of small raised granulations similar to those of *L. billingsi*, but coarser. Crown more elongate than in that species, the relative height to width at IIBr being 1 to 1 as against 1 to 1.4; the anal plate and flat, short arms also perfectly distinguish it. It has the same irregularity in number of IBr found in *L. facietatus*, having 2 in three rays, and 1 in two rays. Maximum crown, 13 mm. high by 10 mm. wide at top of RR; width of column facet, 2.5 mm.; height of B to R to IBr, 3:4:1.

This form is represented by two well-marked specimens, which come from the extreme south of Gotland in a different locality from that of either of the other Gotland species. The surface ornament is prominent enough to show in the double-sized figures without further magnification as is necessary in *L. facietatus,* and if that character is of any value in this group the two species are distinguished by it, as well as by the thicker walls. The principal specimen has some indication of the depressed areas on the plates shown in Angelin's figures of *L. facietatus.*

*Types.* In the Riks Museum, Stockholm, Sweden.

*Horizon and locality.* Silurian, Wenlock Group, bed *d;* Hoberg, Gotland.

### **Lecanocrinus pisiformis** (Roemer)

*Plate I, figs. 14-36*

*Poteriocrinus pisiformis* Roemer, Silur. Fauna Westlichen Tennessee, 1860, p. 54, pl. 4, figs. *7a-d.*—Shumard, Trans. Acad. Sci. St. Louis, II, 1866, p. 392.—Hall, 20th Rep. N. Y. St. Cab. Nat. Hist., 1868, p. 324; Rev. Ed., 1870, p. 366.

*Arachnocrinus pisiformis,* Meek and Worthen, Geol. Surv. Illinois, II, 1866, p. 177.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 94.—Miller, N. A. Geology and Palaeontology, 1889, p. 224, text-fig. 248; 17th Rep. Geol. Surv. Indiana, 1892, p. 651 (Adv. Sheets, p. 41).

*Cyathocrinus pisiformis,* Whitfield, Geology Wisconsin, IV, 1882, p. 353.

*Lecanocrinus pisiformis,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 3, 1886, p. 227.—Pate and Bassler, Proc. U. S. Nat. Mus., XXXIV, 1908, p. 419.

*Lecanocrinus hemisphericus* Rowley, Amer. Geologist, 1904, p. 281, pl. 16, figs. 17, 18, 19.

A small species. Crown subglobose, widest about the middle of RR; in 25 specimens the average height at top of RR to greatest width is 1 to 1.3; constricted distally, so that the average height to width of 12 specimens at IAx is 1.3 to 1; base rounded. Calyx walls thin. Surface generally smooth, but good specimens show a very fine granular network seen only under a strong magnifier. Height and width of complete crown in average specimen, 8 by 8 mm.; maximum specimen at top of RR, 9 mm. high by 11 mm. at middle of RR; minimum specimen at same level, 3.5 by 4, and at IAx, 4.5 high by 3 wide; width of column facet, 2 mm.

IBB small, not protuberant, scarcely visible in side view. BB small. Anal *x* long, narrow, once and a half as long as wide, projecting not over about a third of its length above the radials. RR large, four times higher than IBr, and equaling the total height of the folded brachials. Height of B to R to IBr, 3:4:1; large specimen 4.5:5:1. IBr 2. Arms short, flat, diminishing rapidly; second bifurcation not visible in folded crown. Column facet indented. Column small; proximal columnals very long, without intercalated plates.

This species, chiefly from the late Niagaran limestone of Tennessee, bears the same relation to *L. pusillus* of the Waldron shales that *L. facietatus* does to *L. billingsi* in the Wenlock beds of Gotland. It has always been considered a rare crinoid, until Professor Pate in the summer of 1906 collected for me about 225 specimens, mostly from a single locality. Notwithstanding its rarity, however, it has been from the time of Roemer a well-known fossil to the various paleontologists who have collected in that region. The species has a peculiar facies by which it is readily recognized. When the arms are attached the crown is almost a perfect sphere, somewhat constricted at the upper end. The calyx to the upper margin of the radials is three-fifths of the total height of the crown, and the arms are so short, rapidly tapering and infolding, that the second bifurcation is rarely seen—the plates closing in at the summit being the secundibrachs. This juvenile character prevails throughout all the variations in size from the smallest, 3.5 mm. in diameter, to the largest, 11 mm. A large part of the spheroid is taken up by the radials, which occupy over two-thirds the surface of the calyx, while the basals and radianal are small. The anal plate thus becomes proportionally long and narrow; it only projects about one-third its length above the radials, and the projection is shorter and more obtuse in young specimens. The primibrachs are constant at two in 60 rays of 19 specimens having more or less of the arms preserved.

By the above proportions of the calyx plates, as well as by the thinness of the walls, it is well distinguished from *L. pusillus* of the earlier shales. By comparing the numerous figures on the same plate, it will be seen how much larger are basals and radianal in that species, tending to encroach upon the radial circlet, giving it greater width and less proportionate height; so that the anal plate, although projecting for nearly half its length above the calyx level, is nevertheless but little if any longer than wide. There is also a constant difference in the form of the column facet, which in this species is sharply excavated and indented, leaving vertical sides, whereas in *L. pusillus* it is shallow and saucer-shaped; and it is accompanied by more protuberant infrabasals. The stem of the two species is decidedly different, that of *L. pisiformis* being considerably unlike the prevailing form in the genus, and exhibiting in its very long columnals of uniform width without intercalation of short ones between another juvenile character (Pl. I, fig. 16). On an average *L. pusillus* is much the larger species of the two, although specimens of it are found which are smaller than the maximum size of *L. pisiformis*. It has also much stronger and thicker calyx walls (Pl. I, figs. 5, 18).

There is no other described American species with which this one need be compared except *L. hemisphericus* Rowley, which is evidently founded upon a very young specimen of this species. I have figured Professor Rowley's types (Pl. I, figs. 31, 32), and it would be difficult to separate them from many of the Tennessee specimens of like size and proportions. I have also figured two specimens from Jefferson County, Kentucky (figs. 34, 35), which I refer to this species with some doubt. They were in the Lyon collection, found by Col. Lyon in the Niagaran limestone near Louisville, at a horizon considerably higher than that of the Tennessee beds. These two specimens are of maximum size for the species, figure 34 being larger than any from Tennessee; they are somewhat flattened, but appear proportionally wider, and the anal plate broader, than is usual in the species. The strongly beveled edges of the brachials indicate a mature growth, but some approach to this can be seen in other specimens. Both specimens have a little different aspect from those from Tennessee, and the basals are proportionally larger; but they have the same infrabasals, indented column facet, and juvenile proportions of the arms. I am unable to point out constant differences on which to base a new species for them, and I think they must be regarded as representing an advanced stage of growth in the present species.

*L. pisiformis* is more like the Gotland species *L. facietatus* than any other, and I was at first inclined to consider them identical. They have the same thin calyx walls, large radials, and long, narrow anal plate, projecting but little above the calyx; but on comparison the Swedish form has a broader and more truncate base with more prominent infrabasals, and the anal plate is much less angular above.

In this prolific species, as might be expected, some abnormal examples are to be found, and there would doubtless be more but for the fact that in most of the unweathered specimens found in the colony near Decaturville, Tennessee, the sutures are difficult to see. In one the radianal has almost disappeared, only the smallest triangular vestige of it remaining (Pl. I, fig. 27); and two others (figs. 28, 29) have no radianal; these are of especial interest in connection with the literary history of the species.

*L. pisiformis* has been buffeted about considerably in the books. Meek and Worthen very properly demurred to Roemer's reference of it to *Poteriocrinus*, because it has only one anal plate, and they suggested that it might belong to their genus *Arachnocrinus*, then known only from Hall's *Cyathocrinus bulbosus*. Hall in the 20th Regent's Report mentioned

*Poteriocrinus pisiformis* for comparison with specimens from the Wisconsin Niagaran resembling his *Cyathocrinus pusillus,* and afterward made a similar comparison in the 28th Report; he was much struck by the apparent structural resemblance, which was afterward confirmed notwithstanding the errors of Roemer's description. Wachsmuth and Springer followed Meek and Worthen in 1879, but called attention to the fact that the arms were unknown in the species. It was not until several years later when Wachsmuth, collecting in Roemer's old territory in western Tennessee, found a number of specimens of this species (among them one with perfect arms, Pl. I, figs. 14*a, b*), that we saw that it does not belong to the Inadunata at all, but falls readily under the genus *Lecanocrinus,* to which we referred it in 1885.

In 1891 however, S. A. Miller, having a desire to make a new species out of a specimen from Tennessee placed in his hands, which he thought might conflict with the one already well-known from that region, proceeded to get rid of Roemer's species by casting it out of the genus, criticising Hall's allusion to it, and incidently taking a shot at his especial bête noir, Wachsmuth, whose "late reference of it to *Lecanocrinus,*" he declared, "seems to have been without any consideration." His objection was that *P. pisiformis* was described with "only a single azygous interradial." If we were to stand upon a pure technicality and lay aside common sense, we might admit that Miller's contention was tenable, but this is not necessary. In the condition of preservation in which this small species is usually found the sutures are often difficult to see, especially those toward the base, and it so happened that Roemer, out of the four specimens which he had, either failed to observe the radianal for this reason, or had a specimen for his description and figures which was in the precise condition of two of the abnormal specimens that I have above mentioned, viz., without any radianal. And to make the confusion worse, he mistook cracks in the base for sutures where none existed, and evolved a base with five plates instead of three. Nevertheless if any one will take Roemer's figures (of which I reproduce the two important ones, Pl. I, figs. 30*a, b*) and compare them with a set of the specimens as commonly found in the type locality (such as I have illustrated under this species) he will see that beyond the least question the fossil which Roemer was attempting to describe was the same as this.

It may be added for the completion of this history that Miller in this case was hitting at the wrong head. He was dealing with a specimen from the Waldron shales at Newsom, and the species he should have been afraid of was *L. pusillus,* with which his specimen is clearly identical (Pl. I, figs. 12, 13), although *L. pisiformis* is also found occasionally in the shales at that locality.

*L. pisiformis,* like many small and simple forms, had a long life, ranging sparsely from the Laurel limestone through the Waldron shales into the Louisville limestone; but it seems to have culminated in the lower part of the Brownsport limestone of western Tennessee, where it occurs abundantly at one locality near Decaturville. It also has a wide geographical range, following the species of *Pisocrinus* with which it is associated through Tennessee, Kentucky, Indiana, and New York. There is a small species of about the same size and general form found among the casts in the Racine dolomite of the Chicago area which is probably the same, but specimens of it are too imperfect to figure.

*Types.* Roemer's original specimens are in the Mineralogical Museum at Breslau, Germany. These figured now for the correct definition of the species are in my collection.

*Horizon and locality.* Silurian, Niagaran Group, Laurel to Louisville, but chiefly in the Brownsport limestone; Decatur County, Tennessee; near Louisville, Kentucky; Waldron and St. Paul, Indiana; Lockport, New York; Chicago, Illinois; Racine, Wisconsin; and St. Mary's, Missouri.

### **Lecanocrinus bacchus** (Salter)

*Plate II, figs. 25-28*

*Ichthyocrinus Bacchus* Salter, Cat. Cambrian and Silurian Fossils, 1873, p. 126.

A small species. Crown ovoid, widest at IAx, where height to width is 1 to 1.2; at RR, 1 to 1.6; base rounded; rays uniformly increasing in width from RR to IAx. Surface smooth. Maximum crown, 12 mm. high by 11 mm. wide at $IBr_2$; at top of RR, 4.7 by 8 mm.; column facet, 2 mm.

IBB small and slightly protuberant. BB small. Anal *x* and RA both small, the former acuminate above and projecting to nearly half its height above the radials. RR small, barely twice the length of succeeding IBr, and widest at upper margin. Height of B to R to IBr, 2.5:2.5:1.7. IBr 2, large, increasing in width upward continuous with the widening of the radials. IIBr 4 or 5. Arms flat or gently rounded, not tapering rapidly between the bifurcations, and disappearing by infolding at about the fifth tertibrach. Column composed of nearly uniform columnals without visible alternation; a few at the proximal end thinner than those below.

The description of this species is based upon two nearly perfect specimens from the Wenlock limestone at Dudley, one in my own collection (Pl. II, figs. 28*a, b*), and the other in the British Museum (fig. 27). The first of these has some peculiar surface markings in the nature of depressed areas in the middle portion of the plates. Upon the basals the depression conforms to the outline of the plates, but on the radials and brachials it is crescent shaped, curving down from the upper margin. Although very distinct in all the exposed parts, I cannot consider this sculpturing as anything of specific importance; the other specimen figured, in which the surface is in perfect condition, shows no trace of it, and it is also wanting on another less perfect specimen not figured. I am confirmed in this view by the fact that something of the same kind is found occasionally in other species, *e. g.* in *L. macropetalus* (Pl. III, fig. 8*a*). It is also faintly indicated in the basals of *L. lindstromi* (Pl. II, fig. 22*b*), and must have been seen on some specimen of *L. facietatus* to suggest the appearance shown in Angelin's figures on plate 21 of the Iconographica.

The proportions of the plates in the brachial series are such that there is a gradual widening of the rays from the radial to the upper primibrach, producing that lack of differentiation between calyx and succeeding parts characteristic of *Ichthyocrinus*. This aspect is accentuated by the relatively increased length of the primibrachs. In these particulars this species is similar to *L. meniscus* from Tennessee, but differs from that species as well as from *L. lindstromi* in the form of the anal plate.

In J. W. Salter's Catalogue of Fossils in the Geological Museum of Cambridge University, 1873, p. 126, he gives *Ichthyocrinus bacchus* as a manuscript name for a form numbered *a*.528 in the collection, and comments upon it as follows: "The depressed short form and very short plates so much resemble those of *Taxocrinus nanus*, that some close observation is needful to distinguish this, which has no interradial plates, from the former which possesses very narrow ones." The reference to *Taxocrinus nanus*, another unpublished species, does not help much, although I am now aware that it is the form first described by me as *Homalocrinus dudleyensis*, but herein referred to *H. parabasalis*. But I have been favored by Dr. Woods, of the Sedgwick Museum, with photographs of the two specimens bearing Salter's label as the types of his species, one considerably larger than ours (Pl. II, figs. 25, 26).

These show conclusively that it is a *Lecanocrinus* of similar general form to the other specimens I have figured. Being also from the same horizon and locality, I have no doubt of the specific identity of all these specimens, and I prefer to recognize Salter's name rather than to propose a new one of my own.

*Types.* Salter's originals are in the Sedgwick Museum, Cambridge, England. Of the types used herein that of figure 28 is in the author's collection; of figure 27 in the British Museum of Natural History, London.

*Horizon and locality.* Silurian, Wenlock Group; Dudley, England.

### **Lecanocrinus angulatus** n. sp.

*Plate II, figs. 24a-c*

A large species. Crown obconic, spreading gradually from base to $IIBr_3$, where height to width is 1 to 1.3; base truncate, large, not protuberant. Surface smooth. Crown too much distorted for general measurements; 19 mm. high by 24 mm. wide at $IIBr_3$; 9 by 18 mm. at top of radials; column facet, 7 mm.

IBB large, visible in side view. BB large. RA small. Anal *x* extremely large, fully half of it being above the line of the radials; and eight- or ten-sided because abutting upon two and perhaps three pairs of plates beyond the radials. RR small; height of B to R to IBr, 5:5:2.5. IBr 2, large, half as high as RR, and increasing in width; they have an angular median ridge obscure on RR and becoming sharper upward. Column facet as wide as base; not indented.

I have proposed this species for the reception of a very singular form found by Mr. Liljevall among some specimens in the Riks Museum labeled *Ichthyocrinus,* which after cleaning was seen to possess a combination of characters somewhat puzzling as to its generic position. The specimen is abnormal, having only four basals, but the species is not based upon the abnormal features. It belongs to the class of species with small radials and large and widening primibrachs, which produce rays characteristic of *Ichthyocrinus;* and in the angularity of the rays it differs from other species.

The remarkable thing about this crinoid, and that which causes me to direct especial attention to it, is the presence of a well-defined row of interbrachial plates between the rays from the IIBr upward. This is distinctly shown in position in figure 24*a* of Plate II, but the same kind of plates may be seen in figure 24*b* lying scattered between the left posterior and left anterior rays. It is therefore evidently a definite structure in the specimen, which thus exhibits a tendency to take on interbrachial structures inconsistent with the definition of this genus. I have not made this a specific character, because I am disposed to regard it rather as a sporadic development, analogous to the single intercalated plate we sometimes see in *Ichthyocrinus;* it occurs only between the higher brachials, the primary plates not being separated as in genera having regular interbrachials. Therefore even if this should be a constant character the species might still be retained in the genus, where it would represent, as this individual undoubtedly does, a transition form.

*Type.* In the Riks Museum, Stockholm, Sweden.

*Horizon and locality.* Silurian, Wenlock Group, horizon *d;* Dalhem, Gotland.

### **Lecanocrinus meniscus** n. sp.

*Plate I, figs. 37a-c*

A small species. Crown subovoid, widest at IAx; broadly truncate below, and obscurely pentagonal at level of IBr; base broad; height to width at IAx, 1 to 1.6; at RR, 1 to 2.5. Calyx plates thick; surface apparently smooth. Incomplete crown, 11 mm. high at IIBr$_3$ by 11 mm. wide at IAx; width of base at truncation, 6.5 mm.; width of column facet, 3 mm.

IBB very small, entirely concealed by the column. BB large, but only seen as pentagons in a side view, the lower part being abruptly bent inward by the truncation of the base almost at a right angle toward the column. Anal *x* very large, obtusely angular, and rising with a 10-sided figure more than half its height above radials to the level of the first primibrachs. RR small, only once and a half the height of IBr, upper margin widest; height of B to R to IBr, 3.5:4.5:3. IBr 2, large, more than half as high as the radials and increasing in width upward; somewhat gibbous, depressed at the sutures and rounded longitudinally, making the cross-section at their level quinquelobate. Arms unknown beyond IIBr$_3$. Column much smaller than the truncate base, unknown beyond proximal columnals which are short.

This species is described from a single specimen which is remarkably distinct from all other known species. The character of the base alone distinguishes it; the concealed infrabasals and truncate basals constitute a departure from the prevailing habitus of the genus. The brachial series is of an intermediate character in that the radials and primibrachs are less differentiated, and increase more uniformly in width upward than in the typical *Lecanocrinus*. In this character it falls into a group with *L. bacchus* and *L. angulatus;* and with the latter alone it agrees in the great height to which the anal *x* rises. It is a very robust form with thick and heavy plates, in the convexity of which it also differs from other species.

The unique type specimen was found in debris of the Astraeospongia bed of the *Meniscus* limestone, according to Safford's section of the rocks of western Tennessee, now known in part as the Brownsport beds.

*Type.* Author's collection.

*Horizon and locality.* Silurian, Brownsport limestone (part of the *Meniscus* beds); Decatur County, Tennessee.

### **Lecanocrinus waukoma** (Hall)

*Plate III, figs. 20-25*

*Cyathocrinus waukoma* Hall, Adv. Pub. 18th Rep. N. Y. St. Cab. Nat. Hist. 1865, p. 20, pl. (2), figs. 11, 12; reprinted in 20th Rep. N. Y. St. Cab. Nat. Hist., Doc. Ed., 1868, p. 324, pl. 11(2), figs. 11, 12 (Revised Ed., 1870, p. 367, pl. 11, figs. 11-12).—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 87.—Chamberlin, Geol. Wisconsin, I, 1883, p. 191, fig. 50*f*.—Bather, Ann. and Mag. Nat. Hist. (6)IX, Mar. 1892, p. 213; Crin. Gotland, Sv. Vet. Akad. Handl., XXV, 1893, p. 127.

*Lecanocrinus waukoma,* Weller, Bull. IV, Chicago Acad. Sci., pt. 1, 1900, p. 148, pl. 15, figs. 6-10; not fig. 11.

*Lecanocrinus pusillus,* Winchell and Marcy (not Hall, 1863), Mem. Boston Soc. Nat. Hist., 1865, p. 90.

A large species. Calyx low, subhemispheric, rotund below, with nearly vertical sides and flat or concave base; widest about middle of radials, average height to width at top of RR, about 1 to 1.7; crown probably constricted above radials, and short. Base broadly rounded, and usually shallowly concave. Surface unknown, but plates marked by strong ridges radiating from a central node and passing from plate to plate. Complete crown unknown. Maximum specimen, 17 mm. high by 25 mm. wide at top of RR; average specimen about 10 by 17 mm.; width of base at lowest curve of basals in large specimen 10 mm.

IBB large, restricted to the basal concavity, and not visible in side view. BB very large, curving upward and occupying two-thirds the height of the calyx. RA small. Anal *x* low, as wide as high, not rising above level of radials. RR small, not over two-thirds as high as the basals; height of B to R to IBr, 8:5:2. IBr 2; these and succeeding brachials short and wide, unknown above lower IIBr. Column unknown.

This species is only known from internal casts found in the Magnesian limestone at Chicago. The form of the calyx is wholly different from that of the typical *Lecanocrinus,* its broad concave base and extremely large basals having no parallel except in part as to the base in *L. roemeri.* Hall's type specimen figured in the 20th Regent's Report, plate 11, figures 11 and 12, shows a rather protuberant base, but this is not the usual habitus of the fossil; the base seems to be more often concave than flat. It is curious that the casts of this species, occurring in the same matrix as *Ichthyocrinus corbis,* sometimes also show a distortion of the lower part of the calyx, one side hanging lower than the other (Pl. III, fig. 23); but this is by no means frequent.

The strong radiating ridges mentioned by Hall are not confined to the "subradials" (basals), but extend across the margins of those plates and concentrate again at the middle of the radials, marking the course of the dorsal nerve cords. It is probable that these represent similar and perhaps stronger ridges on the outer surface of the plates, which is also a feature not found in any other species.

The small specimen figured by Weller under this species (*op. cit.,* pl. 15, fig. 11) is a different thing, and I have referred it to *Pycnosaccus.*

*Type.* The original of Hall's figure in 20th Report, plate 11, figures 11 and 12, is not claimed by either the American Museum or New York State Museum and its fate is unknown. The specimens figured herein are in the author's collection, except figure 25 which is in the Walker Museum, University of Chicago.

*Horizon and locality.* Silurian, Racine dolomite formation of the Niagaran limestone in the Chicago area; Chicago, Romeo, Lemont and Joliet, Illinois.

### **Lecanocrinus roemeri** Schultze

*Plate III, figs. 30-32*

*Lecanocrinus Roemeri* Schultze, Mon. Echinodermen Eifler Kalkes, 1867, p. 41, pl. 3, figs. 8*a-g*.—Beyrich, Monatsber. Akad. Wiss. Berlin, Feb., 1871, p. 46 (Transl. in Ann. and Mag. Nat. Hist., (4) VII, p. 404.—Quenstedt, Petref. Deutschlands, IV, 1876, p. 516, pl. 108, fig. 27.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 40.—Springer, Jour. Geology, XIV, 1906, p. 491.

A large species. Crown subconical, truncate below, broadly expanding from base, widest about $IBr_1$; average height to width at RR, 1 to 2.5, spread of calyx to same height from 7 mm. at base to 22 mm. Side outline straight or slightly convex; cross-section at IBr pentagonal; base small, sharply excavate. Surface marked by small raised granules and wrinkles; calyx walls moderately thick. Maximum crown, 20 mm. high by 23 mm. wide at IBr; 9 mm. by 22 mm. at top of RR; width of basal cavity, 7 mm.

IBB small, confined to the basal cavity, or visible only as points at the edge. BB relatively large, partly entering the cavity. Anal *x* obtuse above, not rising beyond level of radials; RA small and variable. RR large, greatly increasing in width to the upper face, and flattened, giving a distinct pentagonal perimeter. Height of B to R to IBr, 6:7:2. IBr varying from 1 to 2; very short, but little over a fourth as high as the radials, not increasing in width upward. IIBr usually 4; one more bifurcation visible. Arms flat; brachials short and wide, closing in a low pyramid about the third or fourth IIIBr. Column facet deeply indented, with sharp projecting rim outside the column. Column large, but not filling basal cavity; proximal columnals short, tapering in width downward, without alternation so far as preserved.

The Eifel limestone is considered to be Middle Devonian, and the horizon of this species is therefore above that of *L. soyei,* thus making it the last known survivor of the genus. It is distinguished from that and all other species by the extreme spread of the calyx, as evidenced by the ratio figures of 1 to 2.5 height to width in an average of three specimens. The pentangular calyx caused by the flattening of the radials at the upper part is also peculiar to this form; while in the very small infrabasals and sharply excavated basal cavity it departs from the typical form of the genus. The brachials are the shortest and widest of any species, and the irregularity in number of primibrachs is quite remarkable; in the two specimens having the arms preserved they are as follows, 2-1-1-1-1, 2-1-2-2-1; so that one primibrach is the most frequent number. The column is also very distinct, and shows the thin, tapering proximal columnals so common to the group in general, but lacking elsewhere in this genus. The radianal is almost wanting in the largest specimen, but normal in the other two. The species is extremely rare. I was told by the old Lehrer Kröffges in Prüm, who was one of Schultze's principal collectors, that no specimens except those figured by Schultze were ever found in his time.

*Types.* The originals of Schultze's figures 8*a*, 8*b*, 8*f*, 8*g*, are in the Museum of Comparative Zoology at Harvard College. That of his 8*c* is in the author's collection.

*Horizon and locality.* Middle Devonian, Stringocephalen-kalk; Kerpen, Eifel Mountains, Germany.

### **Lecanocrinus soyei** Oehlert

*Plate III, figs. 27-29*

*Lecanocrinus soyei* Oehlert, Bull. Soc. Geol. France (3)X, 1882, p. 354, pl. 8, figs. 2-2*f*.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 3, 1886, p. 143.—Barrois, Mem. Soc. Geol. Nord., III, 1889, p. 327.

A small species; complete crown unknown. Calyx conical, broadly truncate below; side outline straight or slightly convex; average height to width at top of RR, 1 to 1.4; cross-section circular; base truncate and excavate. Surface ornamented with coarse tubercles visible to the naked eye, coalescing in places into short wrinkles. Maximum specimen, 8.5 mm. high by 11.5 mm. wide at top of RR; base at column facet, 5 mm.

IBB short, visible in side view. BB and RR of about equal height, and RA of ordinary proportionate size. Anal *x* elongate, obtusely angular above, and rising but little above the radials. Superior parts and column unknown.

M. Oehlert states the diameter at top of radials as ranging from 12 to 16 mm. The specimen which he figures as natural size is about 6 by 9 mm., and the enlargement of the others is not stated. None of his figures show the correct form of the anal plate. I have therefore made the description from three specimens in my own collection, in connection with his figure 2. The surface ornament, which is coarser than on any other species, is well shown in one of them (Pl. III, fig. 29), and the anal plate in another (fig. 28*a*). Oehlert's figure 2*f* is incorrect in representing a brachial directly over the anal plate. According to his figure the primibrach is very short, which would indicate a rapidly tapering crown.

The species is well distinguished from all others by its coarse ornament, and from the only other known Devonian species by its more elongate form and greater size of the infrabasals.

*Types.* In the Musée d'Histoire Naturelle, Laval, Mayenne, France. The other specimens figured herein, Plate III, figures 28, 29, are in the author's collection.

*Horizon and locality.* Lower Devonian; Sablé, France.

### **Lecanocrinus magnaradialis** (Weller)

*Plate III, figs. 26a-c*

*Ichthyocrinus magnaradialis* Weller, Geol. Surv. New Jersey, Pal., III, 1903, p. 299, pl. 33, fig. 5.

A small species. Calyx obconical, with large truncate base; sides somewhat curving; height to width at top of RR, 1 to 1.8. Surface destroyed by erosion. Height and width at RR, 6 mm. by 11 mm.

IBB small. BB and RR large. B to R to IBr, 3:5:4.2. RA large, obliquely under right posterior radial, but almost touching right anterior radial. IBr 1 and 2, giving rise to broad, flat rays, of which only two IIBr are in one place preserved. Other parts unknown.

Dr. Weller described this species from a single badly weathered and rusty specimen. The surface is so much eroded that it is difficult to trace all suture lines with certainty, but the structure shown by the figures is substantially correct. The fact that it is from an American Devonian horizon gives to this species especial interest, and it is to be regretted that our knowledge of it is limited to what we can gain from a single imperfect specimen. The shape and size of the radianal suggests a possible affinity with *Clidochirus,* but its position is that of *Lecanocrinus* to which the specimen otherwise conforms. It is of the general type of *L. soyei* from the Lower Devonian of France.

Weller in describing the species noted its resemblance to *Lecanocrinus,* but was deterred from so referring it because he could not detect the anal and radianal plates; but after considerable experience in deciphering obscure fossils of this group I have been able to identify them satisfactorily.

*Type.* University of Chicago.

*Horizon and locality.* Lower Devonian, from cherty layers equivalent to the New Scotland beds of New York; near Pass Ridge, New Jersey.

## **HOMALOCRINUS** Angelin

### *Plate VI*

*Homalocrinus* Angelin, Icon. Crin. Sueciae, 1878, p. 11.—Von Zittel, Handbuch Palaeontology, I, 1879, p. 355; Grundzüge Palaeontologie, 1895, p. 138.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 35; *ibid.*, pt. 3, 1886, p. 143.—Zittel-Eastman, Textbook Palaeontology, 1896, p. 164 (2d Ed., 1913, p. 203).—Jaekel, Zeitschr. deutsch. geol. Ges., XLIX, 1897, p. 46 (separate).—Bather, Rep. British Assoc. for 1898 [1899], p. 923; Treatise on Zoology (Lankester), pt. 3, 1900, p. 189.—Springer, Jour. Geology, XIV, 1906, p. 482.

*Leiocrinus* Springer, Amer. Geologist, XXX, 1902, p. 95.

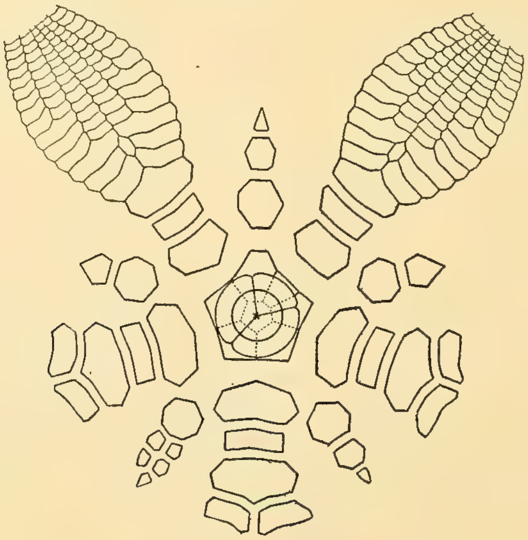

FIG. 13. *Homalocrinus*

Lecanocrinidae with rays partly separated by solid plates arched over by brachials, and with highly specialized base. Crown ovoid. Infrabasals very large, enveloping basals to a variable extent. Radianal under right posterior ray within ring of basals, but may be concealed by the infrabasals. Anal *x* followed by others. Interbrachials usually one large plate followed by others smaller. Primibrachs two. Arms heterotomous; rays divided into ten main rami abutting above interbrachials, with ramules inside of dichotom. Column short, tapering gradually toward the distal end.

*Genotype. Homalocrinus parabasalis* Angelin.

*Distribution.* Silurian, Wenlock beds; Gotland and England.

The history and relations of this genus will be discussed under *Calpiocrinus.*

## **CALPIOCRINUS** Angelin

*Plates VII, VIII*

*Calpiocrinus* Angelin, Icon. Crin. Sueciae, 1878, p. 12.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 38; *ibid.*, pt. 3, 1886, p. 143; Proc. Acad. Nat. Sci. Phil., Nov., 1888, p. 357; *ibid.*, 1890, p. 388.—Von Zittel, Handbuch Palaeontologie, I, 1879, p. 356; Grundzüge Palaeontology, 1895, p. 138.—Zittel-Eastman, Textbook Palaeontology, 1896, p. 164 (2d Ed., 1913, p. 203).—Jaekel, Zeitschr. deutsch. geol. Ges., XLIX, 1897, p. 46 (separate).—Waagen and Jahn in Barrande, Silur. Syst. centre Bohême, VII, 1899, p. 20.—Bather, Rep. British Assoc. for 1898 [1899], p. 923; Geol. Mag., (4) VIII, Aug., 1901, p. 378; Treatise on Zoology (Lankester), pt. 3, 1900, p. 189.—Springer, Amer. Geologist, XXX, 1902, p. 95; Jour. Geology, XIV, 1906, p. 480.

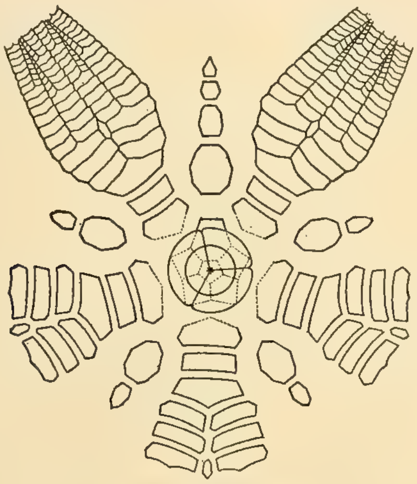

FIG. 14. *Calpiocrinus*

Lecanocrinidae with rays above radials partly separated by solid plates arched over by brachials, and with highly specialized base. Crown ovoid. Infrabasals very large, enveloping basals, and to a variable extent radials and part of primibrachs. No radianal. Anal *x* followed by others. Interbrachials one large single plate, or several smaller ones in succession. Arms heterotomous; rays divided into twenty main rami abutting above interbrachials, bearing ramules inside of dichotom. Column large, short, tapering gradually to an encrusting root.

*Genotype. Calpiocrinus fimbriatus* Angelin.

*Distribution.* Silurian, Wenlock beds; Gotland, Sweden.

The two foregoing genera represent a specialization distinct from anything observed elsewhere among the crinoids, under the influence of which they shade into one another to some extent; therefore they may be discussed together. Considering that they have a definite and highly differentiated structure, no type of crinoids has been more misunderstood than that represented by *Homalocrinus* and *Calpiocrinus*. That it can be better understood now is due largely to the careful working up of the material for structural details, and their instructive illustration, by Mr. Liljevall.

The dominant developmental feature in these two forms is the extraordinary enlargement of the usually inconspicuous and sometimes transitory element, the infrabasals, which is carried to an extreme in both genera. Angelin gave an unusually long diagnosis of *Calpio-*

*crinus,* from which little important information can be extracted beyond one fact on which he laid principal stress, and by which he said the genus was to be distinguished from *Anisocrinus* which it approached in habitus; this is that it had " basalia tria, parabasalia nulla,"—which in current terminology means three infrabasals and no basals. He also noted that the rays and arms were unequal. Wachsmuth and Springer, when redescribing the genus the following year (Revision of the Palaeocrinoidea, pt. 1, p. 38), were much puzzled by the supposed fact indicated by Angelin's description and figures, that this genus differed from all others of the family in having but one ring of plates below the radials. We did not consider that sufficient ground for excluding it, but expressed the opinion that the " lower ring of plates is the analogue of the underbasals, and that the true basals, if not absent, are exceedingly rudimentary "; and added, " we take the small triangular plate which has been called the first anal plate, to be the basal (subradial) on the posterior side, which is larger in the whole family, and that the plates on the four other sides are very minute or only visible on the inside." Considering that neither of us at that time had ever seen a specimen of *Calpiocrinus,* this was not such a bad piece of hypothetical interpretation, as the sequel shows.

Nine years afterward we stated that *Calpiocrinus* was not the aberrant genus which we had supposed from Angelin's figures, but that it had the usual calyx plates of the family—three underbasals and five basals.[1] This remark was based upon specimens obtained by me at Dudley, England, supposed to be *Calpiocrinus,* but afterward described as *Homalocrinus dudleyensis,* and now referred to the type species, *H. parabasalis.* Bather[2] in 1900 stated that *Calpiocrinus* " has minute, often obsolete, IBB, but fairly large BB "; and he separated it from its former associates, *Homalocrinus, Anisocrinus,* etc., placing it in a family Dactylocrinidae along with *Dactylocrinus, Synerocrinus* and *Onychocrinus,* on account of the heterotomous arm structure. He placed *Homalocrinus* with *Anisocrinus* in the family Taxocrinidae.

Since taking up the study of the Crinoidea Flexibilia I have obtained some additional good specimens of this type from Dudley, as well as from Gotland, and have examined a fine series of Dudley specimens in the British Museum. In addition to this, Mr. Liljevall has made for me careful drawings of every specimen of the two genera in the Riks Museum at Stockholm, including new figures of all of Angelin's types. From all these sources of information, it is possible to arrive at a satisfactory understanding of the peculiar structure of these highly specialized crinoids, and it is easy now to see what has been the cause of the former confusion in regard to them.

The facts now disclosed show that Angelin's description was wrong, and that Wachsmuth and Springer's interpretation of the conspicuous ring of plates was substantially correct. As a matter of fact there are two rings of plates below the radials, *i. e.,* both infrabasals and basals; but the remarkable thing about it is that the infrabasals are developed to an extent and in a manner unknown in any other crinoid. The reason why the basals were not seen in the specimens figured by Angelin was not so much their minuteness, or absence on the exterior, as the extraordinary size of the infrabasals which concealed them from view. In many dicyclic crinoids the infrabasals lie wholly within the ring of basals, abutting against them only by their lateral faces; and they are in such cases subordinate in size and position. In some species they are resorbed, and entirely disappear during life. But here they overlap the basals to such an extent as sometimes wholly to conceal them, and not only them, but also the radials and even part of the first primibrachs. The three unequal infrabasals form a relatively enormous growth, far exceeding in size the basals, and enveloping them somewhat after the manner of the centrodorsal in *Thiollierierinus* and in many other comatulids. The actual relation of the two sets of plates is shown in specimens like Plate VIII, figure *7c,* where the infrabasals have been partly removed, and the basals, three out of the five, are plainly visible beneath them. In this specimen the infrabasal development went to the extreme, covering the radials, the larger part of the first primibrachs, and part of the first interbrachials. The structure is also well shown in figure *1b,* on the same plate, where the overgrowth is less extensive; here the radials are not covered, and the posterior basal is slightly visible, while the other basals are concealed except at two places where the edge of the infrabasals has been broken away leaving the points of two basals just peeping out. Another very instructive specimen is that figured on Plate VII, figures *3a, b,* which are exterior and interior views of the base; it shows that the infrabasals, while developed in this extraordinary way on the exterior, retain internally their relative position in the calyx wall, and still lodge the axial canal. It is possible that the relative size of the plates is not quite correctly shown by this specimen, and that the thin edges of the basals, meeting one another laterally, have been somewhat cut away in cleaning the internal surface; the chief surface of apposition of these plates is the outer, or dorsal, surface of the basals, and not their inner face which became quite thin. A vertical section corresponding to figure *3b* shows how this is; Plate VIII, figure 8. The same structure is further shown by figure *4b* on Plate VIII, where the infrabasals are gone, leaving the large pentagonal open space within the ring of basals which they filled, and also the imprint of their outward extension which covered the basals except at small points; this must be considered in connection with figure *4a,* a lateral view of the same specimen, which shows how the basal plates slope inward toward a rather thin edge. These three specimens are also valuable because they show positively the absence of any radianal, the importance of which will be seen when we come to the case of *Homalocrinus.*

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[1] Proc. Acad. Nat. Sci. Philadelphia, Nov., 1888, p. 357.

[2] Lankester's Treatise on Zoology, pt. 3, p. 189.

Now this peculiar basal structure is exhibited in various degrees of development in the excellent material at our command. In some cases two or more of the basals are visible as mere points (Pls. VII, fig. *3a;* VIII, figs. *2c,* 3). In others, and more frequently, the posterior basal which is higher than the others, rising almost to the level of the radials, is alone visible beyond the infrabasals (Pl. VII, figs. *4c, 5d*). In still others no basal at all is to be seen, and the large infrabasals appear to be directly surmounted by the radials (Pl. VIII, fig. *5a*); then the radials almost disappear, and the interbrachials touch the infrabasals by their points (fig. *6a*); and finally the entire radial, with part of the next plate and the lower angle of the interbrachial, are covered over by the upward growth of the infrabasals which form a convex ring like a high, rounded columnal (Pl. VIII, figs. *7b, c*). Nevertheless, the basal elements of the calyx are seen to be the same as those of the group generally. There thus remains no longer any doubt of the real structure of the genus, and it must be considered as representing a definite, though extravagant and therefore short-lived, modification of the crinoid plan in a direction not heretofore observed.

This specialization is shared, however, by the allied genus *Homalocrinus,* in which are exhibited certain transitional features leading up to the fully developed *Calpiocrinus* which are of considerable interest. Angelin's diagnosis of *Homalocrinus* represented a dicyclic crinoid with ovoid body, abutting arms, and " interradial " plates, which was not enough to establish a genus when compared with *Ichthyocrinus* as at that time understood. He did not mention any odd plate such as might constitute a radianal, as he did in his diagnosis of *Lecanocrinus* immediately following, where he said " parabasalia sex "; but he put the two genera into one family called the Homalocrinidae, including also *Clidochirus, Calpiocrinus* and *Anisocrinus.* He also mentioned under *Homalocrinus* that the arms were " dichotomous," being thus different from those of *Calpiocrinus* which he described as being " unequally dichotomous." His description of the only species added nothing to the generic definition. His figure of *H. parabasalis* (Icon. Crin. Suec., p. 11, pl. 16, fig. 29) showed the arms both equally and unequally dichotomizing; and as there was nothing decisive in either generic or specific diagnosis or figures to distinguish it, Wachsmuth and Springer placed it as a subgenus under *Ichthyocrinus* (Rev. Pal., pt. 1, p. 35). Bather in 1900 (Lankester's Treatise on Zoology, pt. 3, p. 189) separated *Homalocrinus* from the Ichthyocrinidae because of its infrabasals, and placed it in his family Taxocrinidae on account of what he supposed from Angelin's figure to be isotomous arms. A correct figure of the type specimen of *H. parabasalis* (Pl. VI, figs. 1*a*, *b*) shows that it has heterotomous arms, with ramules borne on ten main ray divisions, or rami, and a small radianal lying under the right posterior ray between the two basals and meeting the infrabasals. These are the characters which establish its position as a valid genus, and by which it must be distinguished from *Calpiocrinus,* with which it is associated in the remarkable specialization of the basal structures.

When I proposed my brief preliminary analysis of this group in 1902 (American Geologist, vol. 30, p. 95), I mentioned certain specimens from Dudley which had been identified as *Calpiocrinus,* but which on account of the presence of a small radianal observed in them, and of plainly developed basals, I thought might belong to a new genus for which I suggested the name *Leiocrinus. Homalocrinus* was placed in a group with isotomous arms, following Angelin's figures, near *Clidochirus.* The first drawing made for me by Mr. Liljevall from the type specimen of *H. parabasalis* (Pl. VI, fig. 1*a*) disclosed a heterotomy of its arms, which led me then to suppose it must be congeneric with *Calpiocrinus.* A later more detailed study of the base brought out plainly the presence of a small radianal under the right posterior radial (Pl. VI, fig. 1*d*). In this specimen the basals are plainly visible, and it became at once evident that most of my Dudley specimens would fall readily under *Homalocrinus* as characterized by its type specimen and not by former erroneous figures or faulty diagnosis. This I pointed out in my "Further Remarks" in 1906 (Jour. Geology, vol. 14, p. 482), with illustrative figures, and proposed for the Dudley specimens the name *H. dudleyensis.* Since the publication of that paper I have accumulated considerable additional information and material relative to this interesting form, including a new species from Gotland, and am now enabled to make quite plain the generic position of *Homalocrinus,* which was still not entirely clear when I prepared the above-mentioned account of it. It is from the study of a good series of specimens of the Dudley form that the most important light has been obtained. Of these there are nine in the British Museum—where they are known as *Calpiocrinus*—which I personally examined; two in the Sedgwick Museum at Cambridge, England, of which I have photographs and sketches of the essential details; and six of my own;—making seventeen in all from the rocks of the Wenlock age at Dudley. Of these I have figured on Plate VI four from the British Museum and four from my own collection, which thoroughly illustrate the puzzling variations of the species; and there are also shown two other interesting allied Dudley specimens on Plate VII which fall under another species. The study of this series of specimens in connection with the material from Gotland has led to the conclusion that most of the Dudley specimens are only variant forms of Angelin's original species, *H. parabasalis,* and that no reliable diagnostic characters can be pointed out to warrant the retention of the specific name which I proposed for them. While I regret that this long campaign of education as to this form has encumbered the literature with two useless names, the names are gladly abandoned in view of the more important results obtained.

The two decisive generic characters of *Homalocrinus,* as already stated, are the heterotomy of the rays by subordinate branching from the first main division, and the presence of a radianal within the ring of basals. Looking at the figure of *Calpiocrinus fimbriatus* (Pl. VIII, fig. 1*a*), it will be seen that the ray bifurcates into two equal divisions, and each of these divides again into two main branches, or rami, of about equal size, from the inner side of each of which are given off three or more lateral ramules. In *Homalocrinus para-*

*basalis* (Pl. VI, fig. 1*a*) similar ramules are borne directly upon the main branches produced by the first bifurcation of the ray. There are thus in the latter ten main rami, giving off ramules toward the inside of the dichotom; whereas in *Calpiocrinus* there is the same kind of subordinate branching, but it occurs from the second main division of the ray, so that there are twenty such ramule-bearing trunks. In other words the heterotomy in *Homalocrinus* begins on the axillary secundibrach; while in *Calpiocrinus* that bifurcation is substantially equal and the heterotomy begins only on the axillary tertibrach. In each case the outside branch of the respective dichotom remains strong, but diminishes in steps by reason of the successive ramule branching until the final division is equal (Pl. VI, fig. 10; VII, fig. 4*b*); while the inner branches, or ramules, taper gradually to the distal end and become simple, except in some intermediate cases where the lower ramule is enlarged, tending to become an arm, with secondary ramules which are relatively inconspicuous and can rarely be seen at all from the dorsal side (Pl. VII, figs. 1, 2). In the various figures of *H. parabasalis* on Plate VI it will be seen that the lower ramule is relatively the largest, and the series of specimens shows some variation in the size of it. If we had a sufficiently complete series we should doubtless find various stages of its growth, from a relatively small side branch (something like a pinnule) to forms like Plate VII, figures 1, 2, where it is a strong arm, rising to the full height of the ray, and itself having subordinate ramules. If this lower ramule should increase still further until it equaled the size of the outer branch, with its ramules proportionally large, then we should have the perfect arm condition of *Calpiocrinus* (Pl. VIII, figs. 5*a*, 6*a*). Or, conversely, the twenty main rami of *Calpiocrinus* may gradually take on the condition of *Homalocrinus* through a tendency of the inner ramus to abort, thereby losing its own branches and diminishing to the size of a mere ramule. The evolution might go either way, according as it represented progression or retrogression, and in a type otherwise strongly specialized as this is such modifications are to be expected.

In my paper of 1906 I noted a further complication in the definition of the two genera arising out of the apparent inconstant occurrence of the radianal in *Homalocrinus*, which I found to be quite unequally developed in the English specimens, being plainly seen and of good size in some and not visible at all in others. I said, however, that "the difference in this respect may be partly due to the unequal development of the infrabasals, which may sometimes conceal the radianal." This proves to be the correct solution of the difficulty. The radianal in this form is differently located from that in any of the preceding genera, being within the ring of basals and touching the infrabasals, as is the case in *Sagenocrinus*, and in the Inadunate genus *Thenarocrinus;* but it is more primitive because directly under the right posterior ray. It is thus of small size—a low, transverse plate, lying below the lower margin of the radials, much below the angular points of the basals whose ring it shares, and not higher in any event than their lateral margins.

*Homalocrinus*, as has been stated, shares with *Calpiocrinus* the unusual character of the base by which the infrabasals overgrow and conceal the basals and other succeeding plates; and we have already seen that the extent to which this goes in *Calpiocrinus* is variable, sometimes leaving the points of the basals exposed, and sometimes covering not only basals but still higher plates. If there were in *Calpiocrinus* a small radianal lying between the two basals, it is evident that it would be invisible in all cases where the basals themselves were hidden by overgrowth of the infrabasal ring. This is precisely what happens in *Homalocrinus*. Out of the 17 specimens of *H. parabasalis* used in this investigation, eight have the radianal visible, eight fail to show it, and in one the right posterior ray is not exposed. Taking figures 3*a*, *b* on Plate VI as typical of those in which the radianal is visible, it will be observed that the basal plates are well exposed almost to their lateral margins, and the angular lower faces of the radials are in plain view; the radianal, being at the level of the lateral margins of the basals, is accordingly exposed, just as the basals are. In the type, figures 1*a-d,* the radianal is just barely visible, and the basals to an equally small extent. A step farther in infrabasal growth and both radianal and basals (except the posterior) would be shut out (Pl. VI, figs. 13*a, b*).

The sketch at figure 12 on the same plate explains how this might happen in all stages of growth; the dotted line *a* .... *a* represents the line of infrabasal growth in cases where both basals and radianal are left exposed to view; if this line moved upward to *b* .... *b* the radianal would be entirely covered while the triangular points of the basals remained in sight, as in figure 9. And in general it may be stated that where the basals are well exposed nearly or quite to their margins, so that the radials are about clear of the encircling infrabasal ring, we can usually see the radianal; but where the basals appear separated, and covered with the exception of their projecting angles, we cannot. This relation is not absolutely regular, but the facts are sufficient to indicate that it is the rule, and that the radianal is therefore probably present in all the species.

This is corroborated by the evidence of the Swedish specimens. A second example of *H. parabasalis* has been found since Angelin's time and is now in the Riks Museum—a very perfect specimen much like the type except that the infrabasals are enlarged far enough to overlap half of the radials, so that no part of the basals is visible (Pl. VI, figs. 2*a, b*). Here, of course, the radianal has also disappeared, just as would have happened in the type species (fig. 1*d*) if the infrabasals had grown a little higher up. In still another Gotland species, which I have described as *H. liljevalli,* we have two specimens, in one of which the basals and radianal are visible (Pl. VI, figs. 14*a, b*), and in the other both are completely buried (figs. 13*a, b*). There is an analogous case in *Ichthyocrinus gotlandicus,* where the radianal is sometimes invisible simply because covered by the column.

This proof seems to be sufficient to establish the radianal as a constant character of *Homalocrinus;* but the question pertinently follows, why may it not equally exist in *Calpiocrinus,* which would be simply in the condition of those *Homalocrini* in which the radianal cannot be seen? For answer we must recur to the specimens on Plate VIII already mentioned, figures 4*a, b,* and especially to that of figures 7*a-c* which we know has the fully developed *Calpiocrinus* arm structure; these show that in two of the most characteristic species there is no radianal.

This, however, does not end the difficulties we encounter in endeavoring to adjust the long confused relations between these two genera. I have, as I think, satisfactorily accounted for the old and new species of *Homalocrinus;* but our troubles begin again when we undertake to deal with the described species of *Calpiocrinus.* Leaving out the incorrect statement about the basals, and all characters which are of family rank or are mere individual details, the characters assigned by Angelin to the two genera may be stated as follows:

*Homalocrinus:*
1. iBr 1, large, heptagonal; 2 smaller, in series.
2. Anals 3, subequal.
3. Arms repeatedly dichotomous.

*Calpiocrinus:*
1. iBr few, unequal.
2. Anals variable, in longitudinal series.
3. Arms short, wide, unequally dichotomous.

It is evident that the first two specifications of both are wholly indecisive, as they might concur in the same specimen. This leaves only the third to be considered. Supposing this specification in *Homalocrinus* to mean *equally* dichotomous, we know from the type specimen of his only species that this is contrary to the fact, and therefore the third in *Calpiocrinus* would apply to it also. There would thus be nothing in the diagnosis by which to distinguish the two genera; and upon these facts alone *Homalocrinus,* being the first described, would stand. We have therefore to look to the specimens themselves, and not to the diagnoses of Angelin, for the separation of the two genera. Under *Calpiocrinus* he described four species. One of them, *C. humilus,* may be left out of consideration as not possibly belonging to either genus. There remain *C. heterodactylus, C. ovatus,* and *C. fimbriatus,* which appear in this order in the Iconographia. Angelin did not designate any type species, and it seems probable from the statement of Lindstrom and Lovén in the introduction to that work that the order of arrangement of the species was theirs, and not Angelin's. In these circumstances, if a generic definition can be made out for *Homalocrinus* from the characters disclosed by its known species, and if it be further found that the species referred by Angelin to *Calpiocrinus* do not agree with each other as to the corresponding character, but that some of them in this respect approach *Homalocrinus* as now defined,—then it seems to me that any species remaining which clearly differs from the latter in the character in question will be the true *Calpiocrinus;* otherwise *Calpiocrinus,* being the second of the genera in order of publication, would have to be dropped altogether.

Now it so happens that one of these species, *C. fimbriatus,* meets the last condition, and also contains within itself the most complete development of the one character mentioned by Angelin which is left for the genus, viz., the unequally dichotomous arms. And when in addition to this it is remembered that this particular form of heterotomous arm is associated with the lack of a radianal, while its presence is correlated with the other form of heterotomy in the typical species of *Homalocrinus,* it would seem that upon these facts the genus may be logically maintained, with *C. fimbriatus* as its type species.

The position of *C. ovatus* and *C. heterodactylus* remains to be settled. There is but a single specimen of each that is certainly known to belong to them, viz., the respective types, which I have carefully refigured on Plate VII giving four principal figures of each besides some details. The two specimens are of similar type, except that in general form one is more ovoid than the other. In each the basals are completely covered by the infrabasals, except the truncate apex of the posterior basal which connects with the anal plate; no radianal is visible, but this does not prove that it is wanting, because the development is such as to conceal it even if present in the same form and size as in Plate VII, figure 3. In both, the rays divide a second time on secundibrachs 3 or 4 into two nearly equal divisions, the outer one of which bears conspicuous ramules, with bifurcations plainly visible from the dorsal side; while the inner, although large and rising to the full height of the outer one, shows little evidence of lateral ramules from the dorsal side. They are present, however, though much smaller, and are given off from small shoulders of the axillary tertibrach toward the ventral side. This is well explained in *C. ovatus* by figure 4*f,* Plate VII, an enlarged side view of the axil on the exposed inner arm of figure 4*a,* and by figures 4*d, e* showing the axil seen from above and from the side at *b* on another inner arm. The same structure for *C. heterodactylus* is shown in figure 5*e,* where *b* and *c* are axils on the inner arm seen partly in a side view, and *a* a much larger ramule on the outer arm on which also the bases of ramules are plain enough from the dorsal side. The difference between the inner and outer branches is somewhat less in figures 5*a, b* than in 4 *a, b.*

Hence there is in these specimens an arm structure which is of a character similar to that of *Calpiocrinus* as typified by *C. fimbriatus,* but not quite the same. It is a departure in a direction which if continued far enough would result in the disappearance of the inner arm by reduction to the grade of a simple, unbranched ramule of size proportionate to the others following it. This would leave the ray composed of only two ramuliferous trunks, as in *Homalocrinus parabasalis.* Conversely, as already stated, the change might result from the progressive enlargement of the lower ramule of *Homalocrinus.* These specimens, therefore, may represent morphologically degraded *Calpiocrinus,* or advanced *Homalocrinus.* If we knew positively the fact about the radianal in them the line might be more satisfactorily drawn. While we cannot, as already explained, say whether it is or is not present in specimens like these, we must do the best we can with indirect evidence.

We have a fragmentary specimen from Gotland, labeled in the Riks Museum *C.* (*heterodactylus* ? or *ovatus*), with only part of the calyx preserved but showing both interior and exterior surfaces free from the matrix; views of both are given, Plate VII, figures *3a, b.* The exterior view, *3a,* shows small points of three basals, the largest presumably the posterior; but this presents the very unusual peculiarity of not connecting with the anal *x,* the radials closing in above it instead. The interior view, *3b,* confirms this interpretation, all the basals being angular above; and it shows the further important fact that in this form there is no radianal. It will also be noted that in this specimen the large first interbrachials are not elongate and truncate above, as in many of the others, but are rather broad, and angular above, as if followed by two series of plates. Turning now to figures *1a-c* and *2* on the same plate, representing two perfect specimens from Dudley, it will be observed that they both have the same peculiar base, viz., the posterior basal angular above and not connecting with the anal *x;* which is a very unusual thing in this group where generally the posterior basal is greatly enlarged and often rises to the full height of the radials. These two specimens have also the same broad, angular interbrachial, followed by two plates—differing in this respect from the other *Calpiocrini.* The correlation of these two characters gives reasonable ground for assuming the specific identity of the Dudley and Gotland specimens.

Passing now to the arm structure, we see that the two complete specimens are in about the same stage of development as *C. ovatus* and *C. heterodactylus*—the inner branches of the ray being reduced to the size of a greatly enlarged ramule. Having in these specimens—which must necessarily be placed in a distinct species—this condition of arm structure associated with absence of the radianal, it seems reasonable to suppose a like association to exist in the case of *C. ovatus* and *C. heterodactylus,* and that they may therefore upon fairly tenable ground be retained under *Calpiocrinus. H. liljevalli,* on the other hand, in which the inner arm is somewhat less like an arm and more like a ramule, is placed under *Homalocrinus* because we find a radianal in one specimen. It is a close question, and if we had a large number of specimens we should probably find a variety of intermediate stages in which these characters would be combined in many distracting ways for our perplexity. The same may be said, however, of all closely related genera, and it is simply a question of expediency—to be decided, I think, for each case according to its own circumstances—whether to retain such genera upon their typical forms or to throw them together on account of their close transitions. If anyone has devised any exact rule which will regulate all such cases, I have yet to see it.

As an original proposition, my inclination would be to range all these species under one genus in which, under the influence of high specialization, characters elsewhere important have lost their value. But as the two genera, long ago proposed by Angelin, have been recognized in the literature ever since, it will create less confusion to retain them.

With this understanding of the real character of the type represented by these two genera, there is little need for comparing them with others to which they have been supposed by various authors to be related. The interbrachials are not so prominent as in *Anisocrinus,* and there is consequently not that ventricose swelling of the calyx below the arms; they are large enough, however, to give a marked ovoid rotundity to the lower part of the crown, and the rays therefore do not widen upward from the base as in *Ichthyocrinus.* There are usually two or more plates in vertical series, but sometimes the first interbrachial in *Homalocrinus* is followed by two small plates, or series of plates, abreast; either form is quite in contrast to the one huge interbrachial of *Anisocrinus.* The manner of infolding of the arms also differs; instead of bending squarely to a broad, truncate summit so noticeable in that genus, they curve more gradually to a rounded and often narrow apex at a higher point in the arms.

*Homalocrinus* is one of two genera of the Lecanocrinidae in which the tegmen has been observed. It is very well shown in a specimen of *H. liljevalli* found by Mr. Liljevall among some fragments in the Riks Museum (Pl. VI, fig. 15*b*). The dorsal cup is broken off just below the axillary primibrachs, and thus the inner surface of the disk is thoroughly exposed. The tegmen is constructed as usual in the Flexibilia, consisting of a plated integument, with five orals surrounding an open central space from which the ambulacra pass out between the orals to the arms. Two of the ambulacra and all the orals are well preserved, as is also the interambulacral integument. This structure is in every substantial particular the same as that in *Taxocrinus* discovered and described by Wachsmuth and Springer nearly 30 years ago.

The type represented by these two genera was not of long duration, as nothing like it is known later than the Silurian in which it appeared. It was evidently also much restricted geographically, not having as yet been recognized in America, where so many other of the rare and specialized Swedish genera are now known to occur. Eight species have been recognized, of which three are placed under *Homalocrinus* and five under *Calpiocrinus*. They may be arranged as follows:

### THE SPECIES OF HOMALOCRINUS

- I. Arms in 10 main rami, bearing ramules.
  - Ramules simple, gradually diminishing.
    - Crown ellipsoid; iBr in one series.......................................*H. parabasalis.*
  - Lower ramule branching, much enlarged.
    - Crown subglobose; iBr in more than one series above first............*H. liljevalli.*

### THE SPECIES OF CALPIOCRINUS

- II. Arms in 20 main rami, bearing ramules.
  - Inner arm of dichotom less developed than outer.
    - Post. B angular, not touching anal *x*.
      - iBr in two series above the first..............................*C. intermedius.*
    - Post. B truncated by anal *x*.
      - iBr in one vertical series.
        - Crown ovoid ................................................*C. ovatus.*
        - Crown oblong ......................................*C. heterodactylus.*
  - Main rami equal.
    - Post. B truncate. iBr in vertical series.
      - Crown ellipsoid, plates uneven, convex.........................*C. fimbriatus.*
      - Crown ovoid, plates evenly curved............................*C. rotundatus.*

### *Insertae sedis*

(?)*Homalocrinus peculiaris*.....................................Plate VII, figs. 6*a-e*.

### **Homalocrinus parabasalis** Angelin

*Plate VI, figs. 1-12*

*Homalocrinus parabasalis* Angelin, Icon. Crin. Sueciae, 1878, p. 11, pl. 16, figs. 29, 30.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 35.—Springer, Jour. Geology, XIV, 1906, p. 482, pl. 7, fig. 9.
*Taxocrinus nanus* Salter, Cat. Cambrian and Silurian Fossils, 1873, p. 126.
*Homalocrinus dudleyensis* Springer, Jour. Geology, XIV, 1906, p. 482, pl. 7, figs. 12, 13.

Type of the genus.

A small species. Crown ellipsoid, rounding to an obtuse apex above; gradually expanding from base to about upper IIBr, where height to width is about 1 to 1.5; at IAx, 1 to 2.5; base broad, truncate, with spread of calyx to IAx about 1 to 3. Surface smooth. Maximum crown, 17 mm. high by 12 mm. wide; base, 5 mm.; minimum, 9 by 5 mm.; average height to width about 1.5 to 1.

IBB much enlarged, more or less enveloping basals. BB usually visible as small triangles, posterior one highest. RR wider than IBr, touching iBr by short, sloping shoulders. IIBr 2 or 3; IIIBr 4 or 5; average height to width of brachials about 1 to 2.5. Arms above IIBr rounded, generally abutting but not closely packed; ramules on every fourth or fifth brachial, gradually diminishing upward. Anal *x* not larger than other iBr, usually followed by one or more smaller plates in vertical series, filling the interradius; interbrachial sutures somewhat depressed and brachial plates convex, giving more or less unevenness to the general surface. Column short, large, tapering slightly; composed near the calyx of prominent short, rounded columnals, with one or sometimes more, shorter and narrower ones interposed; all become short and about uniform in lower part.

Besides the type, only a single specimen has been found in Gotland referable to this species, and in that the growth of infrabasals has entirely covered the basals and lower half of the radials (Pl. VI, figs. *2a-c*). The posterior basal is not well developed, as the posterior radials meet below the anal plate. This specimen has only two secundibrachs, which is unusual but occurs exceptionally in specimens from Dudley and also in another species. Angelin's figure of the type specimen (Icon. Crin. Suec., pl. 16, fig. 29) is incorrect as to the arm branching, which is represented as partly equal and partly unequal.

A careful study of the excellent material at my command has convinced me that there is no constant diagnostic character by which most of the specimens found at Dudley can be distinguished from this species, and that the specific name *H. dudleyensis,* which I applied to them in 1906, must be dropped.

The specimens to which Salter gave the manuscript name *Taxocrinus nanus* belong to this species, as has been clearly shown by examination of two specimens bearing his label as types, $\frac{a}{527}$, in the Sedgwick Museum at Cambridge, England.

As compared with most other species of this and related genera, this may be considered fairly abundant, yet it must be remembered that the 17 specimens used in the present investigation comprise about all that have been found in nearly a hundred years' collecting at Dudley.

*Type.* Angelin's original, and the other specimen from Gotland now figured, are in the Riks Museum, Stockholm. Of those on Plate VI, figures 5, 6, 7 and 8 are in the British Museum, and figures 3, 4, 9, 10 and 11 are in the author's collection.

*Horizon and locality.* Silurian, Wenlock Group, horizon *d;* Wisby, Island of Gotland, and Dudley, England.

### **Homalocrinus liljevalli** n. sp.

*Plate VI, figs. 13-15*

A small species. Crown subglobose, widest about the upper IIBr, where height to width is 1 to 1.8; at IAx, 1 to 2.4; expending broadly from base to IAx, with spread of calyx 1 to 2.4. Side outline convex; base broadly truncate. Rays deeply rounded and heavy looking. Surface smooth. Maximum crown, 19 mm. high by 18 mm. wide; base, 6 mm.

IBB large, wholly or partly enveloping BB and RA. IIBr 2 or 3; IIIBr 2 to 4; ramules above this mostly on second or third Br. Height to width of Br about 1 to 2. Main arm trunk bearing five or six ramules before infolding, the lower one half as large as the main arm, and branching once or oftener. Arms all deeply rounded, not closely abutting, and not tapering rapidly; their plates convex leaving interbrachial spaces relatively much depressed. Anal *x* not specially different from first iBr in other areas, except for small truncation to meet post. B. First iBr large, obtusely angular above and followed by double series of two to four ranges of small plates, filling the interradius; iIIBr usually present. Tegmen composed of small irregular plates forming a pliant disk, with five large oral plates not in contact surrounding a central mouth, and ambulacra passing out between them and branching to the ten main arms. Column unknown.

The discovery of the tegmen in a fragmentary specimen of this species has been mentioned in the generic discussion. This important fragment did not belong to any species known at the Riks Museum, and I was at a loss where to place it until I received from Mr. Liljevall a second figure (Pl. VI, fig. 15*a*) giving a side view of the rays. Then I saw that it was identical with two very good specimens of an undescribed species from Gotland which had been in my possession for several years; I am thus enabled to illustrate the species very thoroughly. It is beautifully distinct from *H. parabasalis.* There is a certain heaviness and lack of definite taper to the arms which gives it an entirely different aspect; while the generally shorter intervals between the ramules, and the double rows of small interbrachials, afford tangible structural grounds of distinction. The latter character is constant in the three specimens, and as my second specimen is quite small we may conclude that it is not a matter of individual growth. In this species finally we have an evident convergence in the arm structure of *Calpiocrinus* and *Homalocrinus,* and at the same time confirmation of their generic distinctness. The lower ramule of the primary dichotom, which is here quite large, gives off one or two lateral sub-ramules; this can be seen on the two inner ramules of the original of figure 13*a,* where the third and seventh brachials are axillary. On the other specimen, figure 14*a,* bifurcation can be seen at the second brachial. Figure 13*a-b* has the *Calpiocrinus* base with the infrabasals covering everything but the apex of the posterior basal, so of course no radianal is to be seen there; but the other specimen, figure 14, is less developed in that way, the basals being well exposed and slightly unequal. In addition to this the infrabasals are broken away, leaving the lower sloping faces of the basals open; and here we see the radianal fully developed in the position where we should expect to find it. This, I think, must be accepted as proof to justify holding this species under *Homalocrinus,* but with an evident tendency toward the other genus.

*Types.* The type specimens for this species are those of figures 13 and 14 in the author's collection, and of figure 15 which is in the Riks Museum, Stockholm.

*Horizon and locality.* Silurian, Wenlock Group, horizon *d;* Wisby, Island of Gotland.

### **Calpiocrinus intermedius** n. sp.

*Plate VII, figs. 1-3*

Small, but larger than the next following species. Crown ovoid, broadly rounded below, widest about upper IIBr, where height to width is about 1 to 2, narrowing rapidly from there to an apex; spread of calyx from base to IAx, 1 to 2.8. Base rather narrow; side outline strongly convex. Surface smooth. Maximum crown, 30 mm. high by 20 mm. wide; base, 6 mm.

IBB greatly enlarged, usually covering the basals except the apex of post. B. BB small; post. B angular above and not touching anal *x*. RR large, connecting above post. B. IIBr 3 or 4; IIIBr 4 or 5. Average height to width of Br about 1 to 3. Rami unequal, the inner ones of the ray smallest; rounded, strongly tapering, rather closely abutting, infolding to a small apex above the fourth or fifth ramule. Ramules on outer arm of ray about every fourth or fifth Br; inner arm resembling an enlarged ramule with subordinate ramules not visible from dorsal side. Anal *x* not touching post. B and not larger than first iBr in regular areas; iBr one rather short, broad plate followed by more than one series of small plates abreast. Column large, short, terminating in an expanded encrusting root; composed near the calyx of prominent short, rounded columnals, with one to three shorter and narrower ones interposed, all becoming short and about uniform toward the distal end.

This species, like the next, represents a modification in arm structure from *Homalocrinus* toward *Calpiocrinus* in the enlargement of the lower ramules of the dichotom, and has also an infrabasal development sufficient to cover all the regular basals, and any possible radianal. It is clearly intermediate in position, and upon the visible characters might be placed under *Homalocrinus*, but for the probable absence of a radianal. In the basal structure it goes a step further than any other species, to a quite unusual condition in which the anal *x* does not touch the posterior basal, but is cut off both externally and internally by the meeting of the two posterior radials below it. Thus although anal structures are present, the posterior basal is not touched or truncated by them, but remains angular, without any distal connection.

This feature is constant for the three specimens, and is found elsewhere only in the genus *Cleistocrinus* from the same horizon.

In arm structure this form is much in the condition of *Homalocrinus liljevalli*, but in addition to having longer intervals between the ramules there is a perceptible difference in general appearance—the rays in this having a more decided and graceful taper. This is well shown by the beautiful specimen illustrated on Plate VII, figure 1*a*, which is the finest and most complete example of this type yet found. It is wholly free from the matrix and is but little flattened by pressure, so that the natural contour is correctly shown. It has what is so rarely found in this group, a perfect stem, with the root complete—a broad spreading structure evidently for attachment to other objects. The stem is very short, as was probably the case with most of the Silurian genera of this group, indicating that they lived in shallow water. The accompanying specimen, figure 2, with the stem almost complete, is from a very fine, somewhat flattened specimen in the British Museum, the largest one that has been found. The third specimen, from which we obtain a satisfactory elucidation of the basal structure, and proof of the absence of a radianal, is a fragment in the Riks Museum. The reasons for associating these three specimens have been given in the generic discussion. No others have been found.

*Types.* Author's collection, British Museum, and Riks Museum, as above stated.

*Horizon and locality.* Silurian, Wenlock Group; Dudley, England, and Gotland, Sweden.

### **Calpiocrinus ovatus** Angelin

*Plate VII, figs. 4a-f*

*Calpiocrinus ovatus* Angelin, Icon. Crin. Suec., 1878, p. 12, pl. 16, figs. 17-19.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 39.—Springer, Jour. Geology, XIV, 1906, pl. 7, fig. 4.

Specimens small. Crown ovoid, broadly rounded below, widest about axillary IIBr, where height to width is about 1 to 2; at IAx, 1 to 3. Plates evenly curved and but little convex; surface smooth. Height of crown, 26 mm.; width, 18 mm.; base, 5.5 mm.

IBB large, forming a broad, truncate base, concealing all BB except apex of post. B. IIBr 3; IIIBr 4 or 5. All Br much wider than high. Rami nearly equal; ramules from outer arms prominent from every third or fourth Br, those from inner arms inconspicuous, borne upon small faces toward ventral side of axillary Br; outer arms diminishing by steps, inner by gradual taper. Arms closely abutting between rays and ray divisions, infolding about fifth ramule to a rather narrow apex. Anal *x* rather larger than other iBr, followed by two or more plates; first plate in other iBr areas followed by one or more plates in single series. Column unknown.

This species with *C. heterodactylus* exhibits the smallest departure from typical *Calpiocrinus* in the line of transition toward *Homalocrinus*. The inner arms of the ray are almost as large as the outer, differing only in the more gradual taper, and more feeble development of lateral ramules which are rarely visible from the dorsal side. This form is readily distinguished from *C. fimbriatus* and *C. rotundatus* by the above characters, and by the relatively heavier arms and shorter intervals between ramules. We have no proof of the presence or absence of a radianal, the basal development being such that it could not be seen if present; from analogy with *C. intermedius* we assume that it is not. No other specimen but the type has been found.

*Type.* In the Riks Museum, Stockholm.

*Horizon and locality.* Silurian, Wenlock Group, horizon *f;* Gotland, Sweden.

### **Calpiocrinus heterodactylus** Angelin

*Plate VII, figs. 5a-e*

*Calpiocrinus heterodactylus* Angelin, Icon. Crin. Suec., 1878, p. 12, pl. 3, fig. 10, not pl. 26, fig. 8.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 39.—Springer, Jour. Geology, XIV, 1906, pl. 7, fig. 3.—Waagen and Jahn in Barrande, Syst. Silur. centre Bohême, VII, pt. 2, 1899, p. 22.

Similar to *C. ovatus;* differing mainly in having a narrower and less ovoid crown, and in the slightly less development of interbrachial plates. The structural details of this form are sufficiently explained under the last species and in the discussion of the genus. The species is represented by a single specimen, and that not very complete.

*Type.* In the Riks Museum, Stockholm.

*Horizon and locality.* Silurian, Wenlock Group, horizon *f;* Gotland, Sweden.

### **Calpiocrinus fimbriatus** Angelin

*Plate VIII, figs. 1-5*

*Calpiocrinus fimbriatus* Angelin, Icon. Crin. Sueciae, 1878, p. 12, pl. 29, figs. 77, 77*a*, *b*.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 39.—Springer, Jour. Geology, XIV, 1906, pl. 7, figs. 1, 2.

Type of the genus.

Larger than any other species. Crown ellipsoid, widest about the upper IIIBr, and with broad base; height to width at upper IIBr about 1 to 1.5; spread of calyx from base to IAx, 1 to 1.7. Plates convex, and arms rounded. Surface smooth. Maximum crown, 33 mm. high by 23 mm. wide; base, 6 mm.

IBB large and prominent, forming a broad, truncate base, overlapping BB except small points and the truncate apex of post. B. Rays divide a second time on IIBr 3 or 4 into equal branches; first ramule on inner arm usually from 4th IIIBr, and on outer from 6th; ramules above these at intervals of about 6 or 7 Br; arms diminishing by steps for about three ramules to equal final branches, where they infold. Anal *x* large, followed by two or more plates in single series; iBr areas like the anal, but not quite so wide; iIIBr usually present, 1 to 5 small plates in vertical series. Column extremely large, from a third to two-fifths the greatest diameter of calyx; round, composed of very large, rounded columnals about half as long as wide, not alternating or diminishing in width.

This species is the typical *Calpiocrinus* as now defined, having 20 equal arm branches bearing lateral ramules to the inside of the dichotom. The ramules do not branch again so far as observed, but might do so; they have the form of regular arm divisions, closely abutting upon the main ramus and more than half its width. By reason of the successive bifurcations the rami diminish rapidly in size, while the ramules taper gradually, until the branches become equal. Angelin founded the species upon two very good specimens of which I give new and accurate figures. Another fine specimen, with part of the very robust stem attached, has since been obtained in Gotland (Pl. VIII, figs. 5*a-b*) ; it is the largest example of the genus yet found. I have also referred to this species a fragmentary calyx figured by Angelin as *C. heterodactylus* (Pl. VIII, figs. 4*a, b*), which seems to be more like this in the spread of calyx and number of interbrachials. These are all the specimens known.

*Type.* Angelin's originals, and the other specimen now first figured, are all in the Riks Museum, Stockholm.

*Horizon and locality.* Silurian, Wenlock Group, horizon *f;* Gotland, Sweden.

### **Calpiocrinus rotundatus** n. sp.

*Plate VIII, figs. 6-8*

Of the type of *C. fimbriatus,* but differing in the form of the crown, which is ovoid and much more broadly rounded below. The calyx walls are evenly curved, without depressions or unevenness of any kind above the IIIBr, and the lower part of the rays less convex than in the preceding species. Height to width of normal specimen at widest point about 1 to 2, and spread of calyx from base to IAx, 1 to 3. Crown of this specimen, 23 mm. high by 15 mm. wide at $IIBr_2$; base, 5 mm. There is also a difference in the column, which while large is composed of relatively much shorter columnals, with alternation of still shorter ones from the calyx down; it tapers gradually toward the root, and has three internodals in the lower part. Surface smooth.

This species is proposed upon a nearly perfect specimen from Gotland, which is a fine and characteristic example of the genus (Pl. VIII, figs. 6*a-c*), but does not agree with *C. fimbriatus.* It has the stem almost complete; which probably ended in an encrusting root for firm anchorage in shallow waters. I also refer to it another specimen in the Riks Museum which has a considerably shorter and more globose crown; if this is not due to vertical compression, then the difference from *C. fimbriatus* is still further emphasized.

*Types.* Author's collection (Pl. VIII, fig. 6), and Riks Museum (fig. 7).

*Horizon and locality.* Silurian, Wenlock Group, horizon *f;* Bara, Island of Gotland.

### (?) **Homalocrinus peculiaris** n. sp.

*Plate VII, figs. 6a-c*

This singular specimen, which appeared among material collected for me at Wisby, in all probability belongs to the type of the Homalocrinoids. The infrabasals are broken away, but the appearance of the base, when compared with figures 4*b* and 7*c* of Plate VIII, leaves little doubt that they overlapped the basals and reached to the radials. It is peculiar in having but one primibrach, so that the radial is directly succeeded by an axillary, and in the second range there are but two plates, as happens occasionally in *Homalocrinus.* The right posterior ray has an extra plate below the axillary, the lowest one being larger than the radial in the other rays, and this may be taken as a radianal—though relatively too large for that plate in a normal specimen. The heterotomy of the arms is rather that of *Homalocrinus,* with the ramules branching again; and in default of any better disposition we may suppose it to be a specimen of that genus which has dropped one primary brachial all around. So I have concluded to give it a name and let it go at that.

*Type.* Author's collection.

*Horizon and locality.* Silurian, Wenlock Group, horizon *f;* Wisby, Gotland.

## **ANISOCRINUS** Angelin

*Plate X, figs. 1-9*

*Anisocrinus* Angelin, Icon. Crin. Sueciae, 1878, p. 13.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 37; *ibid.*, pt. 3, 1886, p. 143.—Von Zittel, Handb. Palaeontologie, I, 1879, p. 356; Grundzüge Palaeontologie, 1895, p. 138.—Zittel-Eastman, Textbook Palaeontology, 1896, p. 164 (2d Ed., 1913, p. 203).—Jaekel, Zeitschr. deutsch. geol. Ges., XLIX, 1897, p. 46 (separate).—Bather, Rep. British Assoc. for 1898 [1899], p. 923; Treatise on Zoology (Lankester), pt. 3, p. 189.—Springer, Amer. Geologist, XXX, 1902, p. 94; Jour. Geology, XIV, 1906, p. 479.
*Lecanocrinus* Angelin (in part), Icon. Crin. Sueciae, 1878, p. 11.

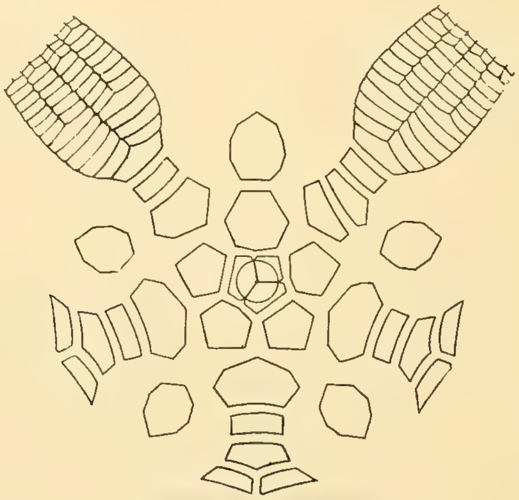

Fig. 15. *Anisocrinus*

Lecanocrinidae with rays partly separated by solid plates arched over by brachials. Crown usually ovoid, truncate above. Infrabasals more or less erect, taking part in the calyx wall. Radianal irregularly under right posterior radial, resting on basals, and generally not touching right anterior radial; exceptionally oblique, or wanting. Anal *x* alone, or followed by others. Interbrachials usually one very large plate (exceptionally more than one smaller in succession) filling the interradius, with rays interlocking above. Primibrachs two. Arms usually dichotomous, interlocking, and infolding almost at a right angle. Column not enlarging at the calyx.

*Genotype*. *Anisocrinus interradius* Angelin.

*Distribution*. Silurian; Sweden and the United States.

*Anisocrinus* may be described as a combination of *Lecanocrinus* and *Clidochirus,* with solid interbrachial structures added. Its most striking peculiarity in typical forms is the relatively enormous first interbrachial plate, usually the only one, completely filling the interradius and closely arched over by the abutting rays.

The calyx plates are rather evenly curved, without marked depressions at the sutures or in the interbrachial region, producing a generally unbroken surface.

The radianal in this genus is in an intermediate position and somewhat inconstant, usually retaining the angular lower face and general form of a radial, but sometimes not touching the right anterior radial, and therefore not quite in primitive position; exceptionally it takes on a quadrangular form and more oblique position, resembling that of *Lecanocrinus*. In one species it is absent, and if we had more satisfactory material I should be disposed to separate this form generically, as it also has a more nearly heterotomous arm than the others. But having only a couple of imperfect specimens, neither of them preserving the base, and in view of the fact that the radianal seems to be otherwise unstable, and that these specimens have the other characteristics of the genus strongly marked, the better course seems to be to leave it as a variant.

The mode of arm branching, or rather the degree of it, is not quite constant. Ordinarily it is a regular dichotomy, the arms dividing into nearly equal halves which are continuations of the preceding branches in the same direction. But in some specimens the division becomes more or less unequal—the smaller branch being toward the inside of the dichotom. This diversity is observed between specimens of the type species; and in the form last above mentioned, where the radianal is absent, the irregularity is so great as to be fairly called heterotomy.

This genus is one of a small group of Silurian genera hitherto supposed to be confined to Gotland, Sweden, which have been vaguely associated in the books, but which on account of the insufficiency and incorrectness of Angelin's figures have been much confused. The others are *Homalocrinus* and *Calpiocrinus,* from both of which *Anisocrinus* differs in the existence or position of the radianal, the larger basal development, and the absence of the remarkable specialization of the infra-base which characterizes those genera. From *Lecanocrinus,* with which it has been most often confused, and *Clidochirus,* it differs in having interbrachials all around instead of only at the anal side.

Although Angelin recognized a new generic form in the specimens he had, his diagnosis contained nothing from which its characters could be inferred, and his description of the type species added no further information; so that from the definition alone the genus would be indistinguishable. To make the matter worse, he referred the best specimen he had to *Lecanocrinus,* without any reason whatever which did not equally apply to the other specimens. It may be supposed that the quadrangular radianal in the smaller specimen (Icon. Suec., pl. 19, fig. 4) suggested its reference to *Lecanocrinus,* of which the author gave a diagnosis calling for " parabasalia sex "; but why he included plate 19, figure 3, which has no radianal at all, and did not refer all the others which have the odd plate to *Lecanocrinus* instead of making a new genus for them, is difficult to see. In addition to this, his figures of *A. interradiatus* (Icon. Suec., pl. 22, figs. 18, 18*a*) were incorrect in failing to show the actual construction of the right posterior ray. So when Wachsmuth and Springer in the Revision of the Palaeocrinoidea undertook to define the genus, the only character of essential importance which they could specify was the arrangement and size of the " interradial " and anal plates;—saying that the description would " probably have to be modified when more species are discovered." We, however, referred Angelin's so-called *Lecanocrinus* to this genus.

Nevertheless the specimens themselves, with the addition of the two since found, show a well-characterized generic form, with a radianal generally present; and this enables us to place the genus upon tenable ground as I pointed out in 1906. This determination has been confirmed by the discovery of two other species in America—both also referred by their describers to *Lecanocrinus.* It is unfortunate that this interesting and well-marked genus should be represented by such a poverty of material—there being only about a half dozen good specimens known in all the species. The typical forms of it have a contour unlike that of any other; the large interbrachials produce a prominent swelling of the calyx, above which the rays contract into a compact bundle of parallel arms which is squarely truncate above by their infolding.

Four species referable to this genus have been described, two from Gotland, and two from America; to these I have added a fifth and doubtful one based on Gotland specimens. The species will be arranged as follows:

### The Species of Anisocrinus

I. Anal and iBr plates 1.
  Crown ventricose at the calyx, contracting above IBr.
    IBB large, protuberant, or in projecting rim; IIBr 3 or 4........*A. interradiatus.*
    IBB small, not visible in side view; IIBr 2..........................*A. angelini.*
  Crown obconic below, gradually expanding beyond IBr.
    IBB large, in conical ring continuous with column....................*A. greenei.*
II. Anal and iBr plates more than one.
  Crown obconic below, gradually expanding.
    IBB visible, not forming rim................................*A. oswegoensis.*
  A doubtful species, variant from the genus, with arms heterotomous
    and no radianal; otherwise like *A. interradiatus*............(?) *A. irregularis.*

## **Anisocrinus interradiatus** Angelin

*Plate X, figs. 1-3b*

*Anisocrinus interradiatus* Angelin, Icon. Crin. Suec., 1878, p. 13, pl. 22, figs. 18, 18*a*.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 37.—Springer, Jour. Geology, XIV, 1906, pl. 6, fig. 9.

Type of the genus.

A small species. Crown ventricose at the calyx, obconic below, contracting and cylindrical above IBr, and squarely truncate at the top—the arms forming a parallel bundle, and squarely infolding about the first to fourth IVBr. Greatest width about the first IBr; height to width at RR, 1 to 2; spread of calyx from base to RR, 1 to 3.5; base obconic, truncate. Surface probably smooth. Maximum crown, 15 mm. high by 11 mm. wide; base, 3 mm.

IBB of good size, protuberant in small conical ring or projecting rim. BB large. RA large, located below r. post. R, usually but not always touching r. ant. R. Anal $x$ very large, acuminate, rising to height of second or third IIBr. iBr not quite so large as $x$. RR larger than BB. IBr short and narrow. Height of B to R to IBr, 3:3.5:1. IIBr 3 or 4, half as high as wide; IIIBr 6 to 8, followed by one bifurcation. Arms closely abutting, evenly rounded, tapering but little; dividing into equal bifurcations each about half the width of the preceding branch, sometimes unequal. Column unknown.

Angelin's figure did not show the radianal, but it is perfectly developed in the type specimen, and also in two others since found (Pl. X, figs. 2*b*, 3*b*); the last of these specimens shows the arms to their full height, which the type did not. All the specimens are apparently smooth.

*Type.* Angelin's original and the other specimens figured herein are in the Riks Museum, Stockholm, Sweden.

*Horizon and locality.* Silurian, Wenlock Group, horizon *f;* Wisby, Island of Gotland.

### **Anisocrinus angelini** Wachsmuth and Springer

*Plate X, figs. 4a, b*

*Lecanocrinus macropetalus* Angelin, Icon. Crin. Suec., 1878, p. 12, pl. 19, fig. 4, not pl. 19, fig. 3, nor pl. 22, fig. 24.

*Anisocrinus angelini* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 37.—Springer, Jour. Geology, XIV, 1906, p. 480, pl. 6, fig. 10.

A very small species. Crown ovoid, rounded below, contracting above the calyx; base broadly rounded, perhaps shallowly concave; greatest width at RR, where height to width is 1 to 1.8. Surface smooth. Crown, 7 mm. high by 5.5 mm. wide.

IBB very small, not visible in side view, perhaps covered by the column. BB larger than RR. RA quadrangular, lying obliquely to left of r. post. R. Height of B to R to IBr, 3:2.2:1.4. IBr about half as high as wide. All brachials proportionally longer and narrower than in other species. Column composed near the calyx of large rounded columnals, with short and narrower ones interposed.

There is only one specimen certainly referable to this species; it is a very small one with the characters of immaturity, and it may be only a variant young specimen of *A. interradiatus*. For some strange reason Angelin figured under the name *Lecanocrinus macropetalus* two specimens for which Wachsmuth and Springer proposed the present species. But a careful examination of these specimens shows that they are not at all alike, and if the species is to be maintained it must be upon the smaller specimen—Icon. Crin. Suec., plate 19, figure 4. Angelin's figures of them are all misleading; his plate 19, figure 4 is about four times enlarged; plate 19, figure 3 and plate 22, figure 24, both drawn from one specimen, are partly restored and incorrect, and the specimen may belong to a different generic type. I have refigured plate 19 figure 4 with two correct drawings, enlarged three times (Pl. X, figs. 4*a, b,* herein). The proportionally longer brachials indicate an immature stage, but the shape and position of the radianal, contour of the lower part of the calyx, very small infrabasals, large basals, and two secundibrachs, afford recognizable differences from the other species.

*Type.* In the Riks Museum, Stockholm.

*Horizon and locality.* Silurian, Wenlock Group, horizon *f;* Gotland, Sweden.

### **Anisocrinus greenei** (Miller and Gurley)

*Plate X, figs. 8, 9*

*Lecanocrinus greenei* Miller and Gurley, Bull. 8, Illinois St. Museum, 1896, p. 52, pl. 3, fig. 28.—Miller, N. A. Geology and Palaeontology, 2d Appendix, 1897, p. 748, fig. 1363.

*Anisocrinus greenei,* Springer, Jour. Geology, XIV, 1906, p. 480, pl. 6, fig. 11.

A rather large species. Crown elongate ovoid, conical below gradually expanding with nearly straight sides to level of RR, where height to width is 1 to 1.5; thence cylindrical, and broadly truncate at the top; spread of calyx from base to RR, 1 to 3; base truncate. Surface smooth. Crown, 19 mm. high by 12 mm. wide.

IBB large, erect, and about continuous with the column, not forming a rim. BB large, RR smaller; height of B to R to IBr, 5:4:2. IBr short, about one-third as high as wide; IIBr 4 or 3, with one more bifurcation visible. Arms infolding at about the sixth IIIBr, equally dividing and closely abutting. Anal *x* large, acuminate, reaching to $IIBr_2$. RA under r. post. R, but rather small, and not touching r. ant. R. iBr not so large as in *A. interradiatus*. Column large, composed of uniformly large rounded columnals without alternation near the calyx.

Miller and Gurley described this species as a *Lecanocrinus* from a single specimen. Neither their figures nor description show the presence of a radianal, yet it is plain in the type specimen (Pl. X, fig. 8). The form lacks the ventricose calyx of the two preceding species, and is of decidedly more elongate and slender habitus, more so than is indicated by the figure, as the specimen is somewhat flattened. The type is derived from the Niagaran limestone near Louisville, Kentucky, and I figure another specimen, from a slightly lower horizon in western Tennessee, which may be of this species, being about the same size and quite elongate, with the same conical infrabasal ring; it is too much distorted for close comparison. No other specimens are known.

*Type.* In the Walker Museum, University of Chicago; the original of figure 9 is in the author's collection.

*Horizon and locality.* Silurian, Niagaran, Louisville and Brownsport limestones; Louisville, Kentucky, and Decatur County, Tennessee.

### **Anisocrinus oswegoensis** (Miller and Gurley)

*Plate X, figs. 7a, b, c*

*Lecanocrinus oswegoensis* Miller and Gurley, Bull. 4, Illinois St. Mus., 1894, p. 33, pl. 3, figs. 15-17.
*Anisocrinus oswegoensis*, Springer, Jour. Geology, XIV, 1906, p. 480, pl. 6, fig. 12.

A small species. Crown elongate, obconic below, gradually expanding to greatest width about IAx, where height to width is 1.1 to 1; at RR, 1 to 3; base truncate. Surface marked by small raised pustules. Crown, 14 mm. high by 8 mm. wide.

IBB of medium size, protuberant, continuous with column and not forming a rim. BB smaller than radials. RA large, directly under r. post. R, touching r. ant. R, and of similar form to radials. Anal *x* obtusely angular above and followed by two unequal plates, with probably others succeeding. iBr two, small, in vertical series. RR large; B to R to IBr, 2.7:3.2:1.5. IBr half as high as wide. IIBr 4 or 3, with at least one bifurcation above. Column unknown.

This species, which is represented by only a single specimen from the Niagaran limestone of Oswego, Illinois, differs from all others in the perfectly primitive position of the radianal, and in the presence of more than one plate in the anal and interbrachial areas. The specimen is somewhat injured; there is an open space in the anal area, but I have no doubt it was filled with plates. The iBr plates taken together are much smaller than the single one of the Swedish species, and there is no such swelling of the calyx as is seen in them. The IBr are proportionately wider plates. This is the only species in which a surface ornament has been observed.

*Type.* In the Walker Museum, University of Chicago.

*Horizon and locality.* Silurian, Maquoketa; Oswego, Illinois.

## (?) **Anisocrinus irregularis** n. sp.

*Plate X, figs. 5-6*

*Lecanocrinus macropetalus,* Angelin, Icon. Crin. Sueciae, 1878, p. 12, pl. 19, fig. 3; pl. 22, fig. 24.

A rather large species, superficially resembling *A. interradiatus.* Crown low, broadly subovate, rounded and ventricose below; cylindrical and truncate above, widest about top of RR, where height to width is about 1 to 2. Surface smooth. Crown about 20 mm. high by 16 mm. wide, but somewhat flattened.

IBB unknown. BB about as large as radials. RA absent. Anal *x* very large, and it may be followed by a small triangular plate. iBr similar in form and size to anal, with similar minute plates sometimes following filling the interradius. RR large; height of B to R to IBr, 5.5:4:1.7. IBr one-third as high as wide. IIBr, 4, with one or two bifurcations following. Rays uniting closely above iBr, dividing unequally, the branches toward the inside of the dichotom being about three-fifths the width of the outside ones; the subordinate branches parallel to the others, closely abutting to them and to each other, and infolding squarely above the second ramule. Column unknown.

I have proposed this species for the reception of the specimen figured by Angelin as *Lecanocrinus macropetalus* in the Icon. Crin. Suec., plate 19, figure 3 and plate 22, figure 24, together with another imperfect one since found, both of which are figured herein. In both specimens the base is broken away, but the other characters are all shown. In the absence of a radianal and the unequally bifurcating arm it presents characters which, if constant, would require the reference of this form to a new genus. But the radianal seems to be a somewhat unstable structure in this genus, having already been found in a variety of positions; and the arm branching is not quite regular, there being some variation in this respect even in *A. interradiatus* where the bifurcation is not always equal. The specimens here described possess the characteristic facies of *Anisocrinus* so strongly, that in the absence of abundant corroborative evidence of constancy in the erratic characters it seems best to retain them within this genus; treating it as a highly specialized type in which, with the predominance of its relatively enormous interbrachial, other characters become inconstant.

*Type.* In the Riks Museum, Stockholm.

*Horizon and locality.* Silurian, Wenlock Group, horizon *f;* Gotland, Sweden.

## HORMOCRINUS nov. gen.

(ὅρμος, necklace; κρίνον, lily)

*Plate XIV*

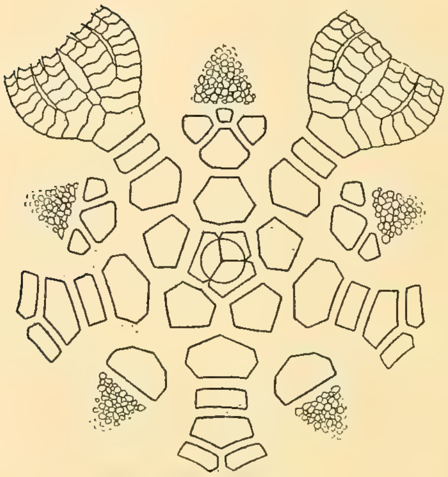

Fig. 16. *Hormocrinus*

Lecanocrinidae with rays above radials partly separated by solid plates followed by perisome. Crown low; calyx well differentiated. IBB erect, taking part in the calyx wall. No radianal. Anal *x* truncate, succeeded by smaller plates abreast, or by perisome direct. Interbrachial areas wide, occupied by one large plate, with or without others succeeding. Primibrachs usually 2, exceptionally 3 or 4; first one filling distal face of radial. Arms dichotomous; rays arching over interbrachial areas but not interlocking. Column large, tapering to a fine point, without attachment.

*Genotype*. *Centrocrinus tennesseensis* Worthen.

*Distribution*. Silurian; United States, England and Gotland.

This genus is proposed for the reception of a fine series of specimens from the Brownsport formation of western Tennessee, and some allied forms from Europe, which could not be brought under any other heretofore known. While superficially resembling *Pycnosaccus* in general habitus, it is broadly distinguished from that genus by the absence of a radianal, and by the presence of a large, solid interbrachial plate abutting on the first primibrach so that the latter plate fills the entire distal face of the radial, shutting it off from possible connection with perisome. This interbrachial may be followed by a few smaller plates, usually only at the shoulders next to the primibrach, or by perisome directly without the interposition of other plates. Like *Pycnosaccus*, it is subject to exception as to the number of primibrachs, which is normally two and nearly constant for the American and English species, but greater and irregular in the single known specimen representing the genus in Sweden.

*Hormocrinus* ought not to be confused with any other genus. Those of the family which are morphologically parallel to it in the absence of a radianal are thoroughly differentiated by other characters. The column in the typical form is peculiar for the small amount of alternation in the columnals, and for its very gradual taper to a small, unbranched, distal end; it was not constructed for permanent attachment to other objects, but was perhaps capable of being wound around them for temporary anchorage. This form of column indicates that these crinoids probably floated about in quiet water, in strong contrast to genera like *Calpiocrinus,* which with their very short, stout column and broad encrusting root, must have lived in shallow water attached to the bottom and contending with currents.

The type species was described by Worthen under *Centrocrinus,* and was subsequently referred by Wachsmuth and Springer to their proposed genus *Idiocrinus*—both on the supposition that it was a Camerate crinoid. The solitary specimen then known did not indicate the Flexible affinities which are so clearly established by the material now in hand.

After this well-defined type had been recognized in the Tennessee specimens it became evident that the genus was widely distributed, and would readily include certain specimens from England and Gotland which had baffled all efforts to refer them to any of the known genera. Thus the genus is represented by a species in each of the well-known Silurian regions of America, England and Sweden; and since the accompanying descriptions were prepared the American range of the genus has been enlarged by the discovery of a specimen closely allied to the type in the Laurel formation at St. Paul, Indiana.

The species may be arranged as follows:

### THE SPECIES OF HORMOCRINUS

I. IBr 2. Calyx ridges angular from RR to BB.
  RR much larger than IBr.
    Surface not pustulose.
      Columnals large, convex, strongly alternating proximally......*H. tennesseensis.*
  RR but little larger than IAx.
    Surface pustulose.
      Columnals short, with slight alternation..........................*H. anglicus.*
II. IBr 3 or more, calyx ridges obscure or wanting.
    Surface smooth.
      Columnals short, with slight alternation.........................*H. gotlandicus.*

## **Hormocrinus tennesseensis** (Worthen)

*Plate XIV, figs. 1-5*

*Centrocrinus tennesseensis* Worthen, Geol. Surv. Illinois, VIII, 1890, p. 95, pl. 14, fig. 1.—Foerste, Jour. Geology, XI, 1903, p. 712.

? *Idiocrinus tennesseensis,* Wachsmuth and Springer, N. A. Crinoidea Camerata, 1897, p. 206, pl. 18, fig. 11.

Type of the genus.

Specimens rather small. Crown short, conical, broadly spreading, with angular ridges marking the course of the dorsal nerve cords and passing from IBB to center of BB, thence coalescing on RR and following median line of Br to the arms; spread of calyx from base to top of RR, about 1 to 3; height to width, 1 to 2. iBr areas depressed, cross-section at IBr pentagonal. Surface without ornament except the ridges. Maximum crown, 12 mm. high by 15 mm. wide; base at IBB, 5 mm.; proximal columnal, 3.5 mm.

IBB large, forming a short, convex cylindrical rim. BB about equal in height to RR. Anal *x* with truncate apex, followed by perisome in the middle and by a plate on each sloping shoulder abutting on IBr$_1$, and IBr$_2$; iBr 1 large plate connecting with IBr, either followed by perisome direct, or by small plates at either side as in the anal area. IBr 2, low, filling distal face of R; height of B to R to IBr as 3.5:3.5:1. IIBr 2; IIIBr 3 or 4. Arms angular to second bifurcation, shortly beyond which they infold. Column large, long, tapering very gradually to a fine point; composed of strong, rounded columnals, with slightly shorter and narrower ones interposed for a short distance from the calyx; beyond this they become nearly equal in size, about two-thirds as long as wide and strongly rounded, resembling a string of beads; near the distal end they lose their convex rim, become straight and much elongated, nearly twice as long as wide.

This species was described by Professor Worthen from a single specimen which did not show the anal side. Nevertheless the form is readily recognized, and the validity of the species is now confirmed by a splendid series of eleven specimens occurring in the Brownsport beds associated with *Pycnosaccus*. The preservation is excellent, leaving little to be desired in the way of structural detail except the interbrachial perisome, which we were not fortunate enough to find intact as in the specimens of that genus, although remnants of it are to be seen in some places. As is shown by the figures, the perisome in some cases directly succeeds the broad truncate interbrachial (Pl. XIV, fig. 2*b*), and in others is separated from it by plates at the lateral sloping faces connecting with the primibrachs. The apex of the large interbrachial, however, remains truncated to some extent, and I am inclined to think that some part of the distal edge of the plate was always in contact with perisome. The number of primibrachs and secundibrachs, two of each, holds good almost without exception in all the specimens of this species; which is interesting as contrasted with their great instability in the Swedish species. The bead-like appearance of the stem for almost its entire length is very marked; after the first few proximals the alternation of the columnals becomes inconspicuous and rather irregular. In the complete specimen shown by figure 3, the stem is preserved to the very end, and there is no sign of any structure for attachment; it ends in a fine point, capable of twisting about other objects.

*Types.* Author's collection.

*Horizon and locality.* Silurian, Niagaran Group, Brownsport limestone; Decaturville, Tennessee. A closely related form occurs in the Laurel limestone at St. Paul, Indiana.

### **Hormocrinus anglicus** n. sp.

*Plate XIV, figs. 6, 7*

Specimens larger than in *H. tennesseensis;* too much flattened to admit measurement of contour, but calyx is similarly low and spreading; much wider than high; spread from IBB to top of RR, about 1 to 3. Delicate ridges pass from IBB and BB to RR, thence following median line of rays to the higher brachials. Crown relatively higher than in that species owing to the greater number of IIBr; approximately about 15 mm. high and 16 wide. Surface distinctly ornamented with small pustules, tending to form longitudinal costae on the brachials and also on the column.

IBB pentagonal in side view. Anal and first iBr rather small, followed by a second range of plates adjoining IBr, probably not meeting at the middle.

BB and RR about of equal height; B to R to IBr, about 3:3:2. IBr 2, low and wide; IIBr 3 to 4, exceptionally less. Column composed near calyx of very thin columnals, slightly alternating for a considerable distance, when they become longer, more uniform, and rounded; they are marked by longitudinal wrinkles and strongly crenulated sutures.

The two specimens on which this species is described are not in the best condition for giving the contours of the calyx and crown, being much flattened, but they are sufficient for clear definition as to all essentials. They have an identical history in one respect; that of figure 7 has been in my collection for several years, having been obtained among some other Dudley material from an English collection, labeled *Taxocrinus tuberculatus;* that of figure 6 was observed by me, when studying the Flexibilia in the British Museum, among a number of specimens of *T. tuberculatus;* it did not seem to fit in that company, and I obtained a cast of it for comparison with my own specimen, which had been decorated with a " ? ". The two lay together unplaced until my specimens from Tennessee came to light, when it was at once apparent where they belonged. This form is evidently very rare at Dudley, as I know of no other specimens. The relatively greater size of the IBr, smaller iBr, more elongate crown, and surface ornament, readily distinguish this from the type species.

*Types.* The original of figure 6 is in the British Museum; of figure 7 in the author's collection.

*Horizon and locality.* Silurian, Wenlock Group; Dudley, England.

### **Hormocrinus gotlandicus** n. sp.

*Plate XIV, figs. 8a-d*

Specimen about the same size as those of the last species; crown more elongate. Calyx low, broadly spreading, without sharp angular ridges or surface markings. Height to width at top of RR, 1 to 2; spread of calyx to same level, 1 to 4; cross-section at IBr strongly pentagonal. Crown at second bifurcation, about 20 mm. high; width at IAx, about 16 mm.

IBB short, not projecting or forming a rim. BB large. Anal and first iBr plates very wide, truncate for their entire width and directly succeeded by perisome, without other plates at the wings. RR relatively low, about as high as BB. IBr half the height of RR, strongly convex and relatively narrower than in other species; variable in number from 3 to 5 in same specimen. IIBr 2 to 3, widely diverging on axillary IBr, which has a truncate apex; this feature extends to the higher divisions which are, so far as seen, strongly divergent. Arms round, without angularity in any part of the ray. Column strong, composed near the calyx of very short columnals of about even diameter, slightly alternating in length.

The species is founded upon a single specimen from Gotland, which is well preserved. The irregularity in number of brachials and the widely divergent arm-branches give it a peculiar aspect, which with the absence of sharp angular ridges readily distinguishes the species.

*Type.* Riks Museum, Stockholm.

*Horizon and locality.* Silurian, Wenlock Group; Alskog, Island of Gotland.

## **CHOLOCRINUS** Springer

### *Plate IX*

*Cholocrinus* Springer, Jour. Geology, XIV, 1906, pp. 515, 517.—Zittel-Eastman, Textbook Palaeontology, 2d Ed., 1913, p. 203.

*Forbesiocrinus,* Angelin (in part), Icon. Crin. Sueciae, 1878, pl. 21, fig. 18 (not fig. 21); pl. 28, fig. 2 (not fig. 3).

*Lithocrinus,* Wachsmuth and Springer (in part), Revision Palaeocrinoidea, pt. 1, 1879, p. 52.

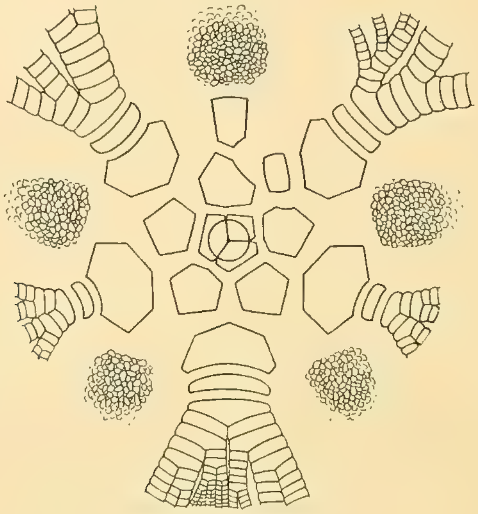

FIG. 17. *Cholocrinus*

Lecanocrinidae with rays above radials separated by perisome only. Crown elongate. Infrabasals erect, taking part in calyx wall. Radianal rhombic, obliquely to lower left of right posterior radial. Anal *x* followed by perisome. Interbrachial areas filled with integument of irregular plates passing into the tegmen. Primibrachs two to five, the first not filling distal face of radial. Arms heterotomous, divergent, not abutting over interbrachial areas; ten main rami with irregular, branching ramules. Column short, cylindrical, with terminal plate for attachment.

*Genotype. Forbesiocrinus obesus* Angelin.

*Distribution.* Silurian; found only in Gotland.

I proposed this genus in 1906 upon Angelin's species *Forbesiocrinus obesus,* as figured on his plates 21 and 28, on account of the different interbrachial structures, and the presence of a radianal as indicated by figure 2 of the latter plate (which proves to be an incorrect restoration). On neither of these characters could it be reconciled with the typical form of *Lithocrinus,* under which that species was ranged by Wachsmuth and Springer in 1879. At that time I was not aware of the facts since brought out by Mr. Liljevall's beautiful preparations and drawings, which confirm the separation of the genus in a very striking manner. The family position of this form is rather difficult to determine. The calyx is that of *Pycnosaccus* in every particular, having wide interbrachial spaces filled only with perisome, an oblique radianal, and a truncate anal plate. But the arms are of a heavy, elongate, divergent type wholly foreign to the Lecanocrinidae generally; upon arm structure alone it would stand next to *Lithocrinus,* with heterotomy less regular than in that genus. Considering the nature of its calyx, and that it has large infrabasals, forming upright pentagons in the calyx wall as typified by *Lecanocrinus,* the genus is perhaps better placed in this family than in the Sagenocrinidae. It also has a short, strong stem with encrusting root, further indicating its affinities to be with shallow water forms like *Calpiocrinus* and *Homalocrinus.*

The interbrachial structures are finely shown by the enlarged detail from the type specimen (Pl. IX, fig. 1*b*), and also clearly indicated in another good specimen (fig. 2*a*). Angelin's principal figures were based upon a single specimen which was badly crushed at the anal side, the posterior basal being pushed under the radial to the left. His figure (pl. 28, fig. 2) takes no account of this, but represents the posterior side with its basal of the same form as the others, and not touching the anal *x* at all. My new figure, 1*c* on Plate IX, shows very clearly what the arrangement of the plates must be, while the fortunate discovery of two other specimens of this rare form removes all doubt upon this point (Pl. IX, figs. 2*b*, 3). In addition to these figures, Mr. Liljevall has made two more enlarged drawings from Angelin's original of *F. obesus,* giving important information as to the anterior ray, and also a series of enlarged figures of the fragment figured by Angelin on plate 26, figures 6, 6*a*, as *F. divaricatus,* which proves to belong to the same form; this is a specimen of much importance, affording complete confirmation of the anomalous arm arrangement indicated by the other specimens, and also disclosing the structure of the tegmen (Pl. IX, figs. 4*a-e*).

The unequal development of the rays in the only known species is a most peculiar feature of this genus. I have not included this character in the generic diagnosis, because the separation is perfectly valid without it, and whether this structure is correlated with the other generic characters or only represents a freak exhibited by a single species may as well be left an open question for future discoveries to settle. There is no doubt that it is perfectly constant in the four well-marked specimens which are known; being in no sense a mere individual irregularity or abnormality, but representing a modification of pentamerous symmetry in a definite way. The anterior and two posterior rays are enormously enlarged, so that they constitute about five-sixths of the brachial equipment—the two antero-lateral rays being dwarfed to a condition of relative unimportance. This may be seen as to the proportional size of these rays at the base by comparison of figure 1*e*, from the large anterior ray, with figure 1*a*, showing the right anterior ray of the same specimen, scarcely more than half the size. Figure 2*a* also gives a good idea of the disproportion between the right anterior ray and the adjacent anterior and right posterior rays which completely overshadow it. This disproportion is, however, really much greater than the mere difference in the width of the primibrachs at the base of the respective rays would indicate; for the two smaller rays in every case are folded under the larger ones, and evidently had little chance to grow. The result is shown best of all by the figure of another specimen in which the five infolded rays are seen at one view (fig. 4*b*). Each of the large rays has by its bifurcations produced four main branches, each fully equal in size to either of the two smaller rays, so there can be no doubt that when fully spread out the combined food-gathering surface of the three large rays would be at least five or six times that of the two smaller ones.

This kind of irregularity in the rays has not been observed before among the Crinoidea Flexibilia, although it is not an uncommon occurrence in the Camerata, as evidenced by the varying number of arm openings. The mode of variation does not seem to follow any fixed rule, except that the increase in number usually occurs first in the posterior rays and afterward in the lateral; the anterior ray usually remaining the longest unchanged. In *Agaricocrinus,* where the simplest form has two arms to each ray, we find successive modifications in four stages by addition as shown in the following table, the upper line representing the posterior rays and the lower the anterior:

| | | | |
|---|---|---|---|
| 2—2 | 3—3 | 3—3 | 4—4 |
| 2—2 | 2—2 | 3—3 | 3—3 |
| 2 | 2 | 2 | 2 |

In *Dizygocrinus* similar modifications occur, the lesser number usually remaining in the anterior ray. In most of the Devonian species of *Megistocrinus,* however, the anterior ray participates in the increase, producing an irregularity similar to that of the present genus, the 16 arm openings being distributed thus:

4—4
2—2
4

This subordination of the lateral rays is really a primitive condition relating to the cystids, and is well shown in the remarkable cysto-crinoid genus *Hybocystis,* in which the lateral rays do not develop any arms, but instead are provided with recurrent ambulacra. In certain Inadunate genera, *Pachylocrinus, Scytalocrinus,* etc., the anterior ray frequently remains simple while the others bifurcate; and in some, *e. g. Atelestocrinus,* it is suppressed altogether.

In all the foregoing cases the equality or predominance of the posterior rays has been maintained, and it would seem as if this were in accordance with a fairly general rule. But by way of further extension of the catalogue of variations, there remains for mention the most curious example of all, where in an isolated species at the close of the Lower Carboniferous the case of *Cholocrinus* is exactly reversed,—the two posterior and the anterior rays being degenerate while the lateral rays are enlarged to double their size. This was described by Whitfield[1] in 1891 as *Cyathocrinus maxvillensis* from three specimens found in the Kaskaskia group. I have a much more perfect specimen from Grayson County, Kentucky, in the collection of the late Col. S. S. Lyon, who had prepared a description and figure of it under one of his favorite hyphenated names, *Poteriocrinus brachialis-irregularis* (it is a Poteriocrinoid, not *Cyathocrinus*). In this specimen the two enlarged lateral arms are preserved to their full length; they are long, ponderous, and simple, while the two posterior rays bifurcate on the first primibrach into a pair of short and delicate arms about half as long as the others. The occurrence of this peculiarity in four specimens from two distant localities removes it from the category of abnormality, and proves it to be a definite structure.

Aside from the inequality of the rays, *Cholocrinus* is interesting for the extreme irregularity of the heterotomy, the ramules being of various sizes, about four to the ray, and not all on the same side of the dichotom; they are at various intervals, sometimes succeeding each other on the same side, and sometimes alternating; and they in turn divide again irregularly.

Interest also attaches to the discovery of the tegmen in one of our specimens of *Cholocrinus obesus,* viz., the original of Angelin's plate 26, figure 6, already mentioned as affording a distal view of the arms. This specimen consists only of the rays, from which the dorsal part of the calyx is broken away leaving the inner floor of the tegmen exposed (Pl. IX, fig. 4*d*); it is of the usual general type for this group, but has very strong ambulacra, somewhat like those of *Onychocrinus,* and is considerably different in detail from the tegmen of *Synerocrinus* and *Taxocrinus.*

Only the one species is known.

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[1] Ann. New York Acad. Sci., vol. 5, p. 577, pl. 13, figs. 5-8.

## **Cholocrinus obesus** (Angelin)

*Plate IX, figs. 1-4*

*Forbesiocrinus obesus* Angelin, Icon. Crin. Sueciae, 1878, p. 9, pl. 21, fig. 18, not fig. 21, nor pl. 28, figs. 2, 3.

*Lithocrinus obesus,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 53.

*Cholocrinus obesus,* Springer, Jour. Geology, XIV, 1906, p. 515.

*Forbesiocrinus divaricatus* Angelin (in part), Icon. Crin. Sueciae, 1878, p. 9, pl. 26, figs. 6, *6a.*

Type of the genus.

Specimens of moderate size. Crown elongate. Calyx well differentiated from the arms, with wide interbrachial spaces; conical, truncate below, composed of strong plates; spread of calyx from base to top of RR about 1 to 2.7; height to width, 1 to 1.5. Surface smooth or coarsely wrinkled. Maximum crown, 35 mm. high by 20 mm. wide; base, 8 mm. Column of small specimen, 20 mm. long.

IBB large, erect, visible as pentagons and forming a conical ring wider than column. BB large, about as wide as high. RA small; anal *x* large, widening upward with truncate and rounded distal margin. RR the largest plates in the calyx, with shallow facets half to two-thirds the width of the plates. IBr short and wide. Height of B to R to IBr, 3:3:1. IBr 2 to 5, the latter number apparently in right posterior ray only. Rays unequal, the anterior and two posterior greatly developed, the lateral small and relatively dwarfed; dividing into two main branches which divide again in the three larger rays, giving off branching ramules at irregular intervals at either side of the dichotom; ray divisions rounded, long and heavy. The two smaller rays covered by the larger ones beyond the second bifurcation. Column short and stout, with expanded encrusting root for attachment to other bodies; prominent rounded columnals project at irregular intervals for the greater part of its length, with several shorter and narrower ones intervening. Tegmen composed of finely plated perisome, with strong ambulacral plates.

Among the irregularities in arm branching for which this species is notable may be mentioned a peculiar difference in the two posterior rays. In the right, a small ramule is given off to the left (outer) side from $IBr_2$, while the main division takes place two or three plates beyond that; in the left the main division is on $IBr_2$ as in the other rays, and the first outer ramule is given off at about the fifth plate above. This is constant in the two specimens in which these parts are well preserved. The figures are based upon four specimens already mentioned in the remarks on the genus; they are new and original drawings by Mr. Liljevall from Angelin's types, two specimens since found, and the fragment of *F. divaricatus*—all from horizon (*f*) at Follingbo. Additional cleaning has brought out clearly the anal side in the type specimen of *C. obesus,* in which the posterior basal, incorrectly drawn in Angelin's figure 2 on his plate 28, is plainly seen with its curved suture next to the radianal (Pl. IX, fig. 1*c,* and sketch 1*d*).

*Types.* In the Riks Museum, Stockholm.

*Horizon and locality.* Silurian, Wenlock Group, horizon *f;* Follingbo, Island of Gotland.

### **ASAPHOCRINUS** nov. gen.

(ασαφής, indistinct; κρίνον, lily)

*Plates IV and X, figs. 10-14*

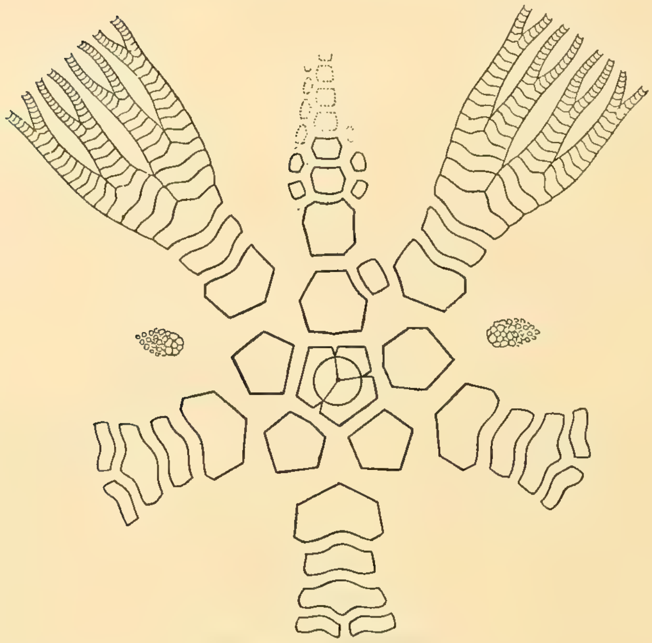

Fig. 18. *Asaphocrinus*

Lecanocrinidae with rays above radials separated by perisome only. Crown turbinate to elongate ovoid. IBB erect, forming part of calyx wall. Radianal rhombic, obliquely to lower left of right posterior radial. Anal *x* truncate or indented above, suturally united with both adjoining rays, and followed by others passing into a tube-like series. Interbrachial areas without definite plates and occupied by perisome. Primibrachs two, exceptionally one. Arms dichotomous, not abutting. Column of moderate size, usually enlarging at calyx, terminating in a branched root.

*Genotype. Asaphocrinus bassleri* Springer.

*Distribution.* Silurian, Niagaran, Rochester shales to Brownsport limestone; United States.

This genus is proposed for the reception of certain well-marked Silurian species which in spite of superficial resemblance cannot be assigned to any hitherto defined. Its affinities are closest with *Pycnosaccus* and *Gnorimocrinus.* It differs from the former in the tube-like series following the first anal plate; and from the latter in the fact that this anal plate is firmly united at both sides to the rays and thus incorporated into the calyx, and that the posterior basal is truncate instead of excavate; this fact precludes reference to the Taxocrinidae. The large and erect infrabasals tend strongly to associate this form with the Lecanocrinidae, which in the typical species it further resembles in the large size of the radials, producing a rather well-differentiated calyx.

The genus embraces two forms from different horizons in the Niagaran Group which diverge rather widely in superficial appearance, both being intermediate as to family characters, but concurring in the most essential of these characters. The first belongs to a numerously represented type from the Rochester shales at Lockport, New York, heretofore described under *Lecanocrinus,* from which it must be removed on account of the lack of lateral contact of the rays, and the presence in varying degrees of a perisomic integument between them. In this form the anal tube is but slightly developed, but its origin is indicated by a curious modification of the anal plate, which for a part or the whole of its length is outwardly curved into a strong longitudinal ridge of the form and size of the tube plates which follow it. These are rarely more than two or three in number, and in many specimens where the posterior rays lie close together they are not visible. In many specimens also the interbrachial perisome cannot be seen, owing to the narrowness of the areas and to the fact that the perisome is deeply imbedded. There is a marked gradation in this feature among the Lockport specimens, some having the areas fairly wide and the perisome readily distinguished, leading up to the later Tennessee form in which it is very conspicuous. The New York form is represented by three species, all from the same horizon and locality, which may be only variants of a single prolific type.

The genus culminated in a fine species recently discovered from the later Brownsport limestone of Tennessee, which I have taken as the type because in it all the generic characters are most fully developed. The interbrachial areas have become very wide, filled with strong perisome like those of *Pycnosaccus,* and with the increased space thus afforded the anal tube has become a prominent object. In both forms there is an evident tendency to modification of the anal structures in the direction of the Taxocrinidae, and as in the cases of *Meristocrinus* and *Synerocrinus* the genus stands near the border line. There is also in both a tendency to irregularity in the number of primibrachs, but this is only sporadic, the normal number generally holding good. In the secundibrachs, however, there is a constant difference between the New York and Tennessee forms.

The four species may be arranged as follows:

### The Species of Asaphocrinus

- I. Anal tube slightly developed; anal $x$ curved into longitudinal ridge.
  - IIBr 3 or more.
    - Calyx not differentiated, low and rounded.
      - iBr areas narrow, with little space for perisome.
        - RR smaller than BB. IBr half as high as RR.................... *A. ornatus.*
    - Calyx not differentiated, more or less turbinate.
      - iBr areas of medium width, exposing perisome.
        - RR smaller than BB. IBr about half as high as RR............ *A. excavatus.*
      - iBr areas narrow.
        - RR larger than BB. IBr very low............................ *A. incisus.*
- II. Anal tube long and well-developed.
  - IIBr 2 (or 1).
    - Calyx well differentiated.
      - iBr areas wide, filled with strong perisome.
        - RR much larger than BB.................................... *A. bassleri.*

### **Asaphocrinus ornatus** (Hall)

*Plate IV, figs. 1-22*

*Cyathocrinus* ? Hall, Nat. Hist. New York, Geol. 4th Dist. 1843, tab. 21, figs. 4, 4*a*.

*Lecanocrinus ornatus* Hall, Nat. Hist. New York, Pal. II, 1852, p. 201, pl. 44, figs. 2*a-m*.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 40.—Springer, Jour. Geology, XIV, 1906, p. 501.

*Lecanocrinus nitidus* Ringueberg, Bull. Buffalo Soc. Nat. Hist., V, 1886, p. 9, pl. 1, fig. 5.

A variable species. Specimens small. Crown elongate, average height to width at IAx about 1 to 1. Calyx low, cup-shaped, differentiated but little or not at all, spreading gradually to top of RR, where height to width in an average of ten specimens is 1 to 1.5. Side outline curved. Anal tube but slightly developed. Surface in well-preserved specimens ornamented with fine pustules; this ornament is very rarely seen, most specimens appearing perfectly smooth. A maximum crown with arms extended is 23 mm. high by 12 mm. wide, and 8 by 12 at top of RR; base at column facet, 3 mm.

IBB fairly large, usually forming a low cup. BB large. RA small. Anal *x* large, truncate or indented above, surmounted by a rounded, longitudinal ridge; followed by one or more plates in series continuous with the ridge, bordered by small plates at one or both sides which are not often exposed. RR relatively smaller than BB, not over twice the length of succeeding IBr. IBr 2, large. Height of B to R to IBr, as 4:3:1.5. IIBr 3 to 5; IIIBr 5 to 10, followed usually by one more bifurcation. Rays rounded, with narrow open spaces between them and their divisions for lodgment of perisome; diminishing rapidly and rather suddenly beyond the third bifurcation into fine, threadlike terminals. Column strong and short, terminating in a branching root for attachment to other bodies; it tapers very gradually from the calyx to the end; a few proximal columnals are usually thin and tapering, especially in young specimens, followed by strong alternation of long curved ossicles with shorter ones, all becoming uniform half way down.

Hall described this species from the Rochester shale at Lockport in 1852, and called attention to the difference in habitus of the rays and arms from that of his other species of *Lecanocrinus*. Dr. Ringueberg afterwards found a number of better specimens in the same shale, from among which he described three species, viz., *L. nitidus*, *L. excavatus*, and *L. incisus*. All this material is now in my possession, reinforced by further accessions from my own collections since made, amounting to a total of about 60 specimens in various positions from those with arms closely folded to widely spread. All are from a small area in the same horizon as the type—the lower part of the shale—and with slight variations largely due to difference in the manner of preservation and maturity of the specimens there is a general similarity of habitus. Many of them are more or less flattened, but a restoration of Hall's principal type, made from the specimen by accurate measurements, gives a contour about the same as that of figures 20 and 21 of Plate IV, which are but little compressed. Some have the arms folded at about the third bifurcation, and others have them extended, which gives them a different appearance but the essential characters remain the same. I am unable to distinguish the type of *L. nitidus* (Pl. IV, fig. 22) from average specimens of *L. ornatus*. The other two species shade into the latter by rather close transitions, and all three may represent merely the variations of a single prolific species flourishing abundantly under favorable conditions.

I have figured one of Hall's types and all of Ringueberg's, and besides these an excellent selection of specimens showing all the variations in age and condition. Throughout them all will be seen the same peculiar anal plate, suturally connected with adjacent plates, but with its incipient longitudinal ridge continued by one or two similarly rounded small plates, marking the change toward the *Taxocrinus* plan. The sudden contraction of the arms just beyond the third bifurcation is peculiar; after that they pass into finials of extraordinary thinness (fig. 17). In further cleaning the type of *L. nitidus* I was much puzzled to find a structure resembling pinnules between the slender arms; but this finally proved to be a minute and perfect specimen of *Homocrinus parvus* entangled among the rays of the larger crinoid; the entire crown, including calyx and complete arms, is only about 11 mm. long (Pl. IV, fig. 22). As to surface ornament, this is so much dependent on the preservation and is so rarely seen that it is useless here for specific characters; as usually found the specimens are smooth.

The narrow interbrachial spaces, less developed anal tube, and greater number of secundibrachs, distinguish this species at a glance from *A. bassleri*.

*Types.* One of Hall's *L. ornatus*, figure 1, is in the Cornell University Museum; the other, figure 2, in the American Museum of Natural History, New York. Those of *L. nitidus*, and the other specimens herein figured, are in the author's collection.

*Horizon and locality.* Silurian, Niagaran, from the *Homocrinus* band in the upper part of the lower third of the Rochester shales; Lockport, New York.

## **Asaphocrinus excavatus** (Ringueberg)

*Plate IV, figs. 23-29*

*Lecanocrinus excavatus* Ringueberg, Bull. Buffalo Soc. Nat. Hist., V, 1886, p. 11, pl. 1, fig. 7.—Springer, Jour. Geology, XIV, 1906, p. 501.

Similar to *A. ornatus*, but with wider interbrachial areas in which the perisome is often readily traced; the specimens are usually larger. The calyx is fairly well differentiated in typical specimens, and is usually rather more turbinate than rounded; height to width at RR, 1 to 1.4; the infrabasals are more protuberant, forming a short cone. Height of B to R to IBr is as 4:3:2.

In all these particulars except the last, the species represents an intermediate stage between *A. ornatus* and *A. bassleri;* in some specimens, such as Plate IV, figures 27, 28, 29, with the interbrachial perisome distinctly shown in fairly wide areas, and the rather prominent infrabasal cone, the facies is strikingly similar to that of the Tennessee form. The transition from *ornatus* is very gradual, and with many intermediate specimens in the collection the distinction is uncertain. A maximum crown is 29 mm. high by 13 mm. wide; base 3 mm.; at top of RR, 9 by 12 mm.; spread of calyx from base, 1 to 4 mm.

*Types.* In the author's collection.

*Horizon and locality.* Silurian, Niagaran, from the *Homocrinus* band in the upper part of the lower third of the Rochester shales; Lockport, New York.

### **Asaphocrinus incisus** (Ringueberg)

*Plate IV, fig. 30*

*Lecanocrinus incisus* Ringueberg, Bull. Buffalo Soc. Nat. Hist., V, 1886, p. 10, pl. 1, fig. 6.—Springer, Jour. Geol. XIV, 1906, p. 501.

Similar to A. ornatus, but of more robust facies, and with calyx well differentiated by reason of the relatively much larger radials, smaller basals, and shorter primibrachs. Height of B to R to IBr is as 3:6:1.5. The calyx spreads less broadly, the height to width at top of radials being 1 to 1.1; and the arms are heavier and shorter. Crown of type specimen is 19 mm. high; 11 mm. wide at RR; base, 3 mm.; this specimen has but one primibrach in two of the visible rays, and in another specimen not figured the anterior radial is an axillary, supporting two rays about as large as the others.

This form is rare, and may be only a sporadic variation in the large colony.

*Types.* In the author's collection.

*Horizon and locality.* Silurian, Niagaran, from the *Homocrinus* band in the upper part of the lower third of the Rochester shales; Lockport, New York.

### **Asaphocrinus bassleri** n. sp.

*Plate X, figs. 10-14*

Type of the genus.

A large species, suggesting a cross between *Pycnosaccus* and *Gnorimocrinus*. Crown about as wide as high, obconical, broadly spreading from base to the level of infolding about the fourth bifurcation. Calyx well differentiated, turbinate or with slightly curved sides; height to width at top of RR, 1 to 1.8; spread from base, 1 to 3.1. Anal tube long, with a strong dorsal series of plates bordered by perisome. Surface smooth. In a mature specimen the crown is 28 mm. high by 26 mm. wide at the distal margin of infolded arms; calyx at top of RR, 8 mm. high by 14 wide; base, 5 mm.

IBB well developed, erect, forming a strong cone. BB much larger, sloping rapidly outward; post. B truncate, followed by large anal *x*, which is without longitudinal curve or ridge. RR twice as large as BB, wider than high; facet for IBr considerably narrower than distal face, leaving strongly sloping shoulders under the iBr areas, which are filled with an integument of plates larger than usual in perisome, yet without definite arrangement. IBr short and wide, varying from 2 to 1 in the same specimen. Height of B to R to IBr, as 3.5:5:2.5. IIBr usually 2, broad and often flat, and nearly as large as IBr. IIIBr and IVBr variable in number, usually about half the size of those preceding, with one nearly equal bifurcation beyond. Column cylindrical, much narrower than the infrabasal disk, not enlarging at the calyx; composed of short, irregularly alternating columnals for a considerable distance downward, beyond which they become longer and uniform.

This species is represented by six good specimens, five of which are figured; they thoroughly exhibit its characters and its irregularities. The anal tube is more or less displaced in most of them, but is best seen in its entirety in Plate X, figures 12, 13. Figures 10*b* and 14 show better the truncate posterior basal and the large first plate, anal *x*, with its sutural connection at each side. There is a strong tendency to reduction in the number of primibrachs, as in *Lecanocrinus* and *Pycnosaccus,* three out of the five specimens having but one in one or more rays. The two-secundibrach feature found to some extent in *Pycnosaccus nodulosus* and *Gnorimocrinus varians* is substantially constant throughout the specimens, with occasional reduction to one. The perisomic integument of the regular interbrachial areas is composed of more substantial plates than usual in this structure; they seem in places to be connected by definite sutural faces, but are without any regular arrangement such as would suggest calling them interbrachials. The fine specimen shown by figure 11 is abnormal on the opposite side, lacking the left anterior ray, apparently from injury during life. An abnormal specimen of *Gnorimocrinus expansus,* Plate XLVII, figure 5, has the anal side almost the same as in this species, but lacks the other characters; and it shows by what close intermediate stages the two genera are related.

The specific name is proposed as a slight acknowledgment of the cordial coöperation in my work which I have at all times received from Dr. Ray S. Bassler, Curator of Paleontology in the U. S. National Museum.

*Types.* In the author's collection.

*Horizon and locality.* Silurian, Upper Niagaran, Brownsport limestone; Decaturville, Decatur Co., Tennessee.

## **PYCNOSACCUS** Angelin

*Plates XI-XIII*

*Pycnosaccus* Angelin, Icon. Crin. Sueciae, 1878, p. 13.—Von Zittel, Handbuch Palaeontologie, I, 1879, p. 356; Grundzüge Palaeontologie, 1895, p. 138.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 41; Proc. Acad. Nat. Sci. Philadelphia, 1890, p. 388.—Zittel-Eastman, Textbook Paleontology, 1896, p. 164 (2d Ed., 1913, p. 203).—Weller, Jour. Geology, VI, 1898, p. 700; Bull. IV, Chicago Acad. Sci., pt. I, 1900, p. 149.—Bather, Rep. British Assoc. for 1898 (1899), p. 923; Geol. Mag., (4)VIII, Aug., 1901, p. 378; Treatise on Zoology (Lankester), pt. 3, 1900, p. 187.—Springer, Amer. Geologist, XXX, 1902, p. 94; Jour. Geol., XIV, 1906, p. 484.

*Oncocrinus* Bather, Ann. and Mag. Nat. Hist., (6)V, 1890, pp. 331, 332; Treatise on Zoology (Lankester), pt. 3, 1900, p. 187.

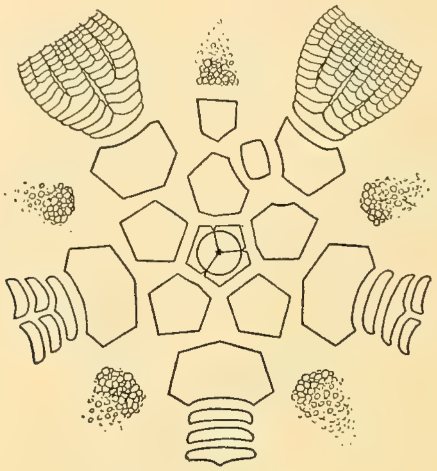

FIG. 19. *Pycnosaccus*

Lecanocrinidae with rays above radials separated by perisome only. Crown short, calyx well differentiated. Infrabasals erect, taking part in calyx wall. Radianal rhombic, obliquely to lower left of right posterior radial, resting on basals. Large anal *x* followed by perisome. Interbrachial areas filled with integument of small plates passing up into the tegmen. Primibrachs varying from one to four, the first not filling distal face of radial. Rays arching over interbrachial areas, but not in close contact. Arms dichotomous, divergent. Column not enlarging proximally.

*Genotype. Cyathocrinites scrobiculatus* Hisinger.

*Distribution.* Silurian to Devonian; Sweden, England, the United States and Canada.

*Pycnosaccus,* although a perfectly well-defined genus, has not been understood heretofore owing to misinformation as to its real structure. Wachsmuth and Springer considered it a doubtful subgenus under *Lecanocrinus,* there being nothing in Angelin's description or figures to distinguish it from that genus except the presence of two primary radials (*i. e.,* one IBr) instead of three, and even on that point it was noted that *Lecanocrinus* sometimes shows the same number. Von Zittel (Handbuch Pal., 1879) followed Angelin's diagnosis. Bather (Lankester's Treatise on Zool., pt. 3, p. 187) placed it under the Ichthyocrinidae as

Impinnata with no iBr along with *Lecanocrinus* and *Ichthyocrinus,* following Angelin whose figures of apparently perfect specimens showed neither interbrachials nor any space for their accommodation. In fact the principal figures of both his species are restorations and incorrect, especially that of the type species, *P. scrobiculatus* (Icon. Crin. Suec., pl. 15, figs. 10, 11). Instead of having the rays rather closely abutting as in his figures 11, 12 and 14 on plate 15, the first primibrach does not fill the distal face of the radial, but leaves shoulders on either side; above which there is a considerable space between the rays. One of the specimens in the Riks Museum examined by Mr. Liljevall shows at the inner margin of this space distinct traces of the articulation of small plates, both in the regular interbrachial areas and above the anal plate (Pl. XI, figs. 9*c, d*).

After receiving these drawings, and having seen the nearly perfect specimen in the British Museum with its wide spaces between the rays above the shoulders of the radials (Pl. XII, figs. 10*a, b*), I concluded that these large interbrachial spaces must have been occupied by an integument of small plates, although they had never been seen, and upon that ground assigned the genus to a definite place in the group now called Sagenocrinidae.[1] This interpretation of the structure was soon afterward definitely confirmed in an unexpected quarter. Up to that time, with the exception of an imperfect specimen described by Weller from the Niagaran of Chicago, our knowledge of the genus was derived from the few specimens found in Gotland and England. It was therefore with no little satisfaction that I found among the collections made for me by Pate from the Niagaran limestone of western Tennessee a number of fine specimens of *Pycnosaccus,* some of them having the interbrachial areas perfectly filled with small plates. The structure of these areas is delicate and fragile as compared with the massive calyx plates and generally robust arms, but it is perfectly preserved in place in several specimens (Pl. XII, figs. 2*a, b,* 3*a, b*), and in one of them some of the small plates are surmounted by sharp nodes (figs. 3*a, b*).

Owing to the absence of definite plates in the interbrachial areas there is a distinct line of demarcation between calyx and arms, which gives to this form an entirely different habitus from any of the preceding, and indeed from most of those in the entire group. Thus understood, the genus stands widely distinct from those with which it has been associated, the only near approaches to it being the anomalous genus *Cholocrinus,* which has a closely similar calyx but an entirely different brachial structure, and its Carboniferous successor, *Nipterocrinus.* Even with the calyx alone it is readily distinguished from *Lecanocrinus* by the character of the radial facets. As in that genus there is a tendency to irregularity in the number of primibrachs, which is utilized as a specific character although not very reliable or sharply defined.

The type species, *P. scrobiculatus,* was described from the calyx alone without any arms or brachials attached, and Angelin's subsequent figure (pl. 15, fig. 11) being as already stated an imaginary restoration as to the arms, was without authority in representing it with a single primibrach. The species is recognized in typical specimens, mostly from Klintberg, horizon *f,* by its prominent ridges on the calyx plates. On one of these Mr. Liljevall found a primibrach in place on two of the rays (Pl. XI, figs. 6*a, b*) but on neither is it an axillary, thus showing that the species may have more than one primibrach. He also found in the Riks Museum a well-marked but unusually large specimen from Wisby, probably of the same horizon, with three rays partly intact, having two primibrachs in two of them and one in the third (Pl. XI, fig. 7). From these two specimens it may be concluded that two primibrachs is the general rule in this species. This is reinforced by the peculiar condition of these parts in *P. nodulosus,* a smaller Gotland form scarcely distinguishable from the former. Out of three specimens with arms one has a single primibrach all around, but the other two have in most of the rays a normal sized axillary, and beneath it a short, thin plate which may be considered an immature or suppressed primibrach (Pl. XI, fig. 11*a*).

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[1] Journal of Geology, vol. 14, 1906, pp. 484, 517.

In the English form, otherwise very similar to some forms of the type species, and another closely related species from Tennessee, the number of primibrachs is constant at one in at least 15 specimens. But the Tennessee collections have yielded a thoroughly distinct species having three and four. In another Gotland specimen which I consider an abnormal *P. nodulosus* there is another irregularity similar to one of those noted in *Lecanocrinus;* the radianal appears in primitive position under the right posterior ray, and the anal *x* has been pushed out of the calyx, being represented by two or three small plates above the level of the radials (Pl. XI, fig. 16*b*).

*Pycnosaccus* is notable as being one of the genera which lack the characteristic enlargement of the upper part of the column so common in this group; the stem is constructed very much like that of *Lecanocrinus.* Thanks to Mr. Liljevall's skillful preparation, we are able to add this to the list of genera in which the structure of the tegmen is known. His fine drawings from a specimen of *P. nodulosus* show it to be of the general type for the group—a plated perisome traversed by ambulacra; as might be expected in such small specimens this is very delicate, the ventral side as shown at the inrolled portion of the arm (Pl. XI, fig. 15*b*) being covered with the smallest imaginable plates; the central part with the orals is not preserved.

The known stratigraphic range of *Pycnosaccus* has been increased by the discovery of a species from the Keyser beds of West Virginia, belonging to the earliest Devonian; and also of an imperfectly known species from the Middle Devonian of the Mackenzie River basin in Canada.[1] The genus is well distributed geographically, being found in Gotland, England and America. *P. costatus,* founded by Angelin on a very small specimen which cannot be found, is clearly a young *P. scrobiculatus.* Weller's imperfect *P. americanus,* from the Niagaran beds at Chicago, is of the same type. *Lecanocrinus calyculus,* from the Niagaran limestone of New York, proves to belong to this genus, as well as a somewhat similar specimen with unusually heavy plates from Chicago, figured by Weller as *Lecanocrinus waukoma. Arachnocrinus canadensis* Whiteaves, from the Devonian of the Arctic region, should also be placed here. Including these and *P. dubius* of doubtful generic position, there are 10 species, which may be arranged as follows:

## THE SPECIES OF PYCNOSACCUS

- I. IBr usually 2.
  - Crown usually small.
    - Calyx turbinate.
      - Calyx angular with sharp ridges connecting centers of plates, and pits at angles where the 3 sutures meet.
        - IBr moderately wide, arms round.
          - Base broad, but not projecting.
            - Anal *x* broad and truncate .......... *P. scrobiculatus.*
    - Calyx ridges obscure.
      - IBr wide, arms heavy.
        - Anal *x* narrow and pointed .......... *P. nodulosus.*
    - Calyx smooth, plates without median elevation; no calyx ridges.
      - IBr wide .......... *P. calyculus.*

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[1] And it has been still further increased in the opposite direction by the acquisition too late for description herein of specimens of a new species from St. Paul, Indiana, thus carrying the genus back to the Laurel formation.

II. IBr 1.
  Crown usually large.
    Calyx turbinate.
      Calyx ridges sharp and narrow, no pits at angles, plates fairly thick.
        IBr moderately wide, arms rather angular.
          R facets often raised, with slight marginal rim.
            Base narrow; lower part of IBB contracted..................*P. patei.*
      Calyx ridges broad and rounded; shallow pits at angles; plates massive.
        IBr rather wide; arms round and heavy.
          R facets not elevated and without rim.
            Base wide. IBB not contracted........................*P. bucephalus.*
      Calyx ridges obscure; no pits at angles.
        IBr narrow—two-fifths the width of R.
          Arms slender, rounded............................*P. tenuibrachiatus.*
III. IBr 3 or more.
  Crown small.
      Calyx low, hemispheric, without ridges or pits.
        IBr moderately wide; arms relatively much longer than
          in other species ..............................................*P. welleri.*

*Species Imperfectly Known*

IBr unknown.
  Calyx ridges present.
    IBB very large; calyx turbinate..............................*P. americanus.*
    IBB small, largely hidden by the column.............................*P. canadensis.*
  Column tapering gradually from calyx; surface smooth..............(?)*P. dubius.*

## **Pycnosaccus scrobiculatus** (Hisinger)

*Plate XI, figs. 1-10*

*Cyathocrinites scrobiculatus* Hisinger, Lethaea Suecica, Supp., II, 1840, p. 6, pl. 39, figs. 4*a*, *b*, *c*; Anteckningar i Physik och Geog., pt. 7, 1840, p. 45.—Bather, Ann. and Mag. Nat. Hist., (6) V, 1890, pp. 387, 388; Crinoidea of Gotland, 1893, p. 12.

*Pycnosaccus scrobiculatus,* Angelin, Icon. Crin. Sueciae, 1878, p. 14, pl. 15, figs. 10, 11.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 41.

*Pycnosaccus ? costatus* Angelin, Icon. Crin. Sueciae, 1878, p. 14, pl. 15, fig. 13.

Type of the genus.

Specimens generally small. Calyx turbinate, with straight sides, wider than high; average height to width about 1 to 1.6; base broad and truncate, spread from base to top of R, 1 to 2.8. The calyx plates are strong, marked by sharp, elevated neural ridges passing from below the radial facets to centers of basals, and from there diverging again to the infrabasals, usually also horizontally from center to center of radials; these ridges divide the surface into large triangular and rhombic areas with their angles at the centers of the plates, leaving depressions in the middle of these areas where three sutures meet. Calyx of size usually found, about 14 mm. high by 23 mm. wide; base, 8 mm.; an unusually large specimen is about 18 mm. high by 30 mm. wide in a flattened condition.

IBB large, visible as pentagons in side view. BB usually higher than RR. RA quadrangular. Anal *x* wide, truncate above. Radial facets moderately wide (to width of R as 1 to 1.8) leaving sloping shoulders for the iBr areas. IBr usually 2; IIBr few, usually 2 or 3. Arms round, fairly thick. Column unknown, but must have been quite large.

The elevated ridges or costae were made by Angelin the principal character both of the genus and species. As compared with other species in which they occur this is usually peculiar in having a horizontal ridge passing from one radial to another (the radial commissure). It is interesting to note that in one Gotland specimen not from the same locality as the others (Pl. XI, figs. 9*a*, *b*) the transverse ridge is wanting, and also the depressed areas at the juncture of the suture lines—the specimen in these respects as well as in the general appearance resembling those from Tennessee. The specimen showing the principal arm structure (fig. 7) is much larger than the others, but it is otherwise characteristic.

Angelin's *P. costatus* was probably a young individual of this species, with a higher calyx and more numerous costae. The figure is shown to be about two and one-half times enlarged, but the specimen cannot be found.

*Types.* Those of Angelin's figures and the others figured herein are in the Riks Museum. Of Angelin's there is only the original of his plate 15, figure 10—his other figure being a restoration.

*Horizon and locality.* Silurian, Wenlock Group, horizon *f*; mostly from Klintberg and Lau, some from Wisby—and perhaps from horizon *d* at the last locality—Island of Gotland.

### **Pycnosaccus nodulosus** Angelin

*Plate XI, figs. 11-16*

*Pycnosaccus nodulosus* Angelin, Icon. Crin. Sueciae, 1878, p. 14, pl. 15, figs. 12, 14; pl. 28, fig. 29.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 41.—Bather, Ann. and Mag. Nat. Hist., (6)V, 1890, p. 387.

A very small species, having little to distinguish it from the preceding except the greater height of RR and width of the radial facet, and the fact that the anal plate is acuminate instead of truncate. The proportionate height of IBB to BB to RR is 1:5:6; width of radial facet to the width of radial is about as 1 to 1.2, the result being that the interbrachial spaces are very narrow. The irregularity in the number of IBr, and the tendency to take on a second one by the intercalation of a very thin or short rudimentary plate beneath the axillary (Pl. XI, fig. 11*a*), has been mentioned in the generic discussion. The costae, while obscure, are plainly in evidence. Angelin gave as the only specific character that the arms are nodulose, but specimens as now prepared and figured show nothing of this beyond the mere convexity of small arm plates. The column, not known in *P. scrobiculatus*, is well preserved in this species; it is large, composed of wide rounded columnals regularly alternating with narrow ones, without any taper near the calyx.

I have figured under this species a peculiarly abnormal specimen, which otherwise could not be assigned to any known genus (Pl. XI, figs. 16*a-c*). In general appearance of the arms and calyx it is similar; and if we treat the lower plate in the right posterior ray as the radianal separated from the anal and developed in its primitive position, while the anal plate is crowded upward beyond the level of the radials, the structure may be consistently interpreted. We have already seen similar abnormalities under *Lecanocrinus.*

*Types.* In the Riks Museum.

*Horizon and locality.* Silurian, Wenlock Group, horizon *f;* Follingbo, Island of Gotland.

## **Pycnosaccus calyculus** (Hall)

*Plate XIII, figs. 6-9*

*Lecanocrinus caliculus* Hall, Nat. Hist. New York, Pal., II, 1852, p. 203, pl. 46, figs. 3*a, b.*—Beyrich, Monatsber. Akad. Wiss. Berlin, Feb., 1871, p. 46 (Transl. in Ann. and Mag. Nat. Hist., (4) VII, p. 404.

*Lecanocrinus calyculus* ? Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 40.

*Lecanocrinus waukoma* Weller (part) [not Hall], Bull. IV, Chicago Acad. Sci., pt. 1, 1900, p. 148, pl. 15, fig. 11 (not figs. 6-10).

A small species; with calyx evenly curved, and not marked by any ridges or pits, but perfectly smooth. It has a wide anal plate slightly rounded distally, projecting somewhat above the line of radials, and in that respect resembling *Lecanocrinus,* under which it was described. But the arms, though wide, are distinctly rounded and not abutting, thus leaving open interbrachial spaces which could not have been occupied by any plates suturally united to the rays, but only by the perisomic integument characteristic of this genus. It has fairly large IBB; IBr 2; IIBr 2 or 3. Arms well rounded. Column strong at the calyx, with well rounded nodals and short internodals, and a very gradual taper distally.

This species was described by Hall from a calyx only, which he erroneously states was from the shales at Lockport, New York. His specimen (Pl. XIII, fig. 6) has all the appearance of a limestone fossil, and this is confirmed by the discovery of my two specimens of precisely the same appearance figured along with it. They are derived from the upper Niagaran (Lockport) limestone, above the shales—a horizon perhaps equivalent to the Racine dolomite of the western Silurian. The fine specimen with arms and stem supplies the details which were unknown to Hall; while somewhat less spreading in the calyx, it agrees perfectly with the other two in the relative proportions of the basal and radial plates.

The specimen referred by Weller to *Lecanocrinus waukoma,* from the dolomite of Chicago, Plate XIII, figures 9*a, b,* is probably a massive variety of this species.

*Types.* Hall's figure 3*a* is in the American Museum of Natural History, New York. The other specimens now figured are in the author's collection.

*Horizon and locality.* Silurian, Niagaran, Lockport limestone; Lockport, New York. Racine dolomite, Chicago, Illinois.

### **Pycnosaccus patei** n. sp.

*Plate XII, figs. 1-9*

Specimens averaging large. Calyx somewhat similar to that of *P. scrobiculatus,* but slightly higher, less sharply angular, the side outline curved instead of straight; there are no pits or depressions at the junction of sutures; the costae are more delicate and usually lack the horizontal ridge connecting the radials. There is a decided and constant difference in the form of the base, which instead of being broad and truncate is narrow, and the lower part of the infrabasal ring is contracted into a neck projecting downward but little larger than the column; on account of this narrow base the spread of the calyx to top of radials is far greater than in the type species, being on an average in 10 specimens about 1 to 4. A well-proportioned mature specimen with arms folded measures: crown, 38 mm. high by 29 mm. wide at top of RR; base at IBB neck, 7 mm.

IBB fairly high, erect, lower part forming a cylindrical rim. R facets narrower than in *P. scrobiculatus,* the average width to that of R being 1 to 1.7; they are somewhat elevated above the general margin of the radials, leaving rather sloping shoulders, and usually having a slight projecting rim along the entire margin of the radials, which perhaps takes the place of the transverse ridge in the Swedish species. IBr 1; IIBr 3 or 4. Arms moderately strong, usually somewhat angular at the back. Column relatively small, about one-fifth the width of calyx at top of RR, and of less diameter than the infrabasal rim; composed of strong rounded columnals with smaller ones interposed somewhat irregularly.

This species is represented by a series of 15 specimens in fine preservation, collected for me by Pate during his quarrying operations near Decaturville, Tennessee, in the summers of 1906 and 1907. They were deposited in a very fine-grained shaly clay favorable to the preservation of structural details, but the fossils are all changed into flint of various colors. In associating the name of Professor Pate with this notable species, I wish to record my appreciation of one of the finest pieces of systematic and scientific collecting that has ever come under my observation.

There is no such instability in the number of primibrachs in this series as in those of Gotland. In the whole series of specimens, all of which have the arms preserved, there is not a single variation from the single axillary plate following the radials. One peculiar feature in this form not very well shown by the figures is an asymmetry in the calyx of many specimens by which the column facet is pointed slightly out of the vertical axis, somewhat as is seen in *Ichthyocrinus corbis.* In this case the inclination seems mostly toward the posterior side, that being a little shorter and less convex than the anterior. In such a strong calyx as this such a distortion would not be due to gravity; but I have no explanation for it.

*Types.* Author's collection.

*Horizon and locality.* Silurian, Niagaran Group, Brownsport limestone, Beech River formation; near Decaturville, Decatur Co., Tennessee. Since these descriptions were prepared a species has been discovered in the Laurel limestone at St. Paul, Indiana, closely allied to this but much more delicate in size and sculpturing.

## **Pycnosaccus bucephalus** (Bather)

*Plate XII, figs. 10-11*

*Oncocrinus bucephalus* Bather, Ann. and Mag. Nat. Hist., (6)V, April, 1890, p. 334, pl. 14, fig. 31; *ibid.*, May, p. 387.

A large and robust species. Similar to *P. scrobiculatus,* but with more massive crown and heavier arms. Calyx more rotund, without sharp angles, with costae much broader and rounder, and no ridge connecting RR; it is somewhat lower proportionally—height to width in two specimens being about 1 to 1.8; spread of calyx from base to top of RR, 1 to 3. Maximum crown, 40 mm. high by 30 mm. wide; base, 10 mm.

IBB low, nearly flat, not contracting above column facet. R facets wide, their width to that of R as 1 to 1.55; but little elevated and without projecting rim. IBr 1; IIBr 2 or 3, and sometimes one. Arms heavy, rounded. Column very large, almost as wide as the infrabasal ring; composed of strong, rounded columnals, with shorter and narrower ones irregularly interposed.

This species was named by Dr. Bather without description as the type of his proposed genus *Oncocrinus,* which he afterward placed as a synonym under *Pycnosaccus* (Lankester's Zoology, pt. 3, p. 187), and the specimens upon which it was founded have been courteously placed by him at my disposal. These consist of two fine individuals from Dudley, originally in the collection of John Gray and now in the British Museum, which are to my knowledge the only ones found. The species agrees with *P. patei* in having uniformly one primibrach, but has a much broader base and larger column, entirely lacking the contraction of the infrabasals so characteristic of that species. It is in every way more robust, the calyx ridges stronger, and the arms heavier and rounder. It is, of course, closely related to that as well as to the Swedish species—the three being from closely correlated horizons, and doubtless representing merely changes due to migration. One of the specimens has an asymmetry of the calyx similar to that mentioned under *P. patei.*

*Types.* In the British Museum.

*Horizon and locality.* Silurian, Wenlock Group; Dudley, England.

## **Pycnosaccus tenuibrachiatus** n. sp.

*Plate XIII, figs. 1-2*

A medium-sized species, resembling *P. patei,* but with more delicate and slender arms. Calyx of about the same proportions, but appearing higher because the arms do not extend quite so high up; base broader, spread of calyx from base to top of RR, 1 to 3. Side outline curved; ridges obscure. Maximum crown 26 mm. high by 20 mm. wide; base, 7 mm.

IBB low, not contracting above column facet. R facets very narrow, their width to that of R as 1 to 2.5; not elevated, shallow and but little indented; distal margins of RR almost perfectly straight. IBr 1; IIBr 2 and 3. Arms round, very short and slender. Column unknown.

This species, from a higher horizon than any of the preceding, is one of the two latest representatives of the genus, bringing its range into the Devonian. It is well distinguished from any of the others by the delicacy of the arms, and by the other details given. Figures 1*a*, *b* show a specimen in which the surface markings are somewhat obscured; that of figure 2 has the ridges very sharp and is strikingly similar to some specimens of *P. patei*, but the form of the infrabasal ring will separate them.

*Type*. Author's collection.

*Horizon and locality*. Devonian, Keyser formation of the Helderbergian; Keyser, West Virginia.

### **Pycnosaccus welleri** n. sp.

*Plate XIII, figs. 3-5*

A small and delicate species, with low hemispheric calyx and relatively long and heavy arms. Calyx without ridges or depressions of any kind; height to width about 1 to 2; side outline convex, and surface evenly curved. Average crown, 16 mm. high by 10 mm. wide at top of RR; base at column facet, 3 mm.

IBB low, nearly horizontal, but little visible in side view, and not projecting toward the column. BB small; RR very large, three-fourths the height of the calyx. R facets about one-half width of R, deeply excavated, with sharply sloping shoulders at either side. IBr 3 to 4, sometimes 2. IIBr 4 to 6. Arms rounded, long, and relatively heavy, tapering but little. Column moderately large, composed of straight columnals of uniform width, with alternation of shorter and longer ones for a short distance from the calyx, beyond which they become of equal length.

This species occurs in the same horizon and locality as *P. patei*. While not so abundant, it is represented by a sufficient number of specimens to show the constancy of its characters. It may be distinguished without difficulty, since it bears little resemblance to typical *Pycnosaccus*, the arms having increased at the expense of the calyx. Wherever in the stem or other characters it departs from the type of *Pycnosaccus* it approaches *Nipterocrinus*, and without the radianal and anal plate it would readily be taken for that genus. The increased number of primibrachs is a well-established character, there being three or more in all the rays of four specimens except in one ray which has two.

Named in honor of Dr. Stuart Weller, of Chicago, whose work upon the crinoids of the Chicago area is a notable contribution to our science, and who was the first to recognize the presence of the genus *Pycnosaccus* in America.

*Types*. Author's collection.

*Horizon and locality*. Silurian, Niagaran Group, Brownsport limestone; Decaturville, Tennessee. A species of this type has recently been found in the Laurel limestone at St. Paul, Indiana.

### **Pycnosaccus americanus** Weller

*Plate XIII, fig. 10*

*Pycnosaccus americanus* Weller, Bull. IV, Chicago Acad. Sci., pt. 1, 1900, p. 149, pl. 15, fig. 12 [*Pycnosaccus ornatus* in explanation of plate 15].

A small species of the type of *P. scrobiculatus*, but with a more elongate calyx, and especially much larger IBB, which are higher than in any other species. The specimen is too imperfect for detailed description.

*Type*. Chicago Academy of Sciences.

*Horizon and locality*. Silurian, Racine dolomite of the Niagaran Group; Chicago, Illinois.

### **Pycnosaccus canadensis** (Whiteaves)

*Arachnocrinus canadensis* Whiteaves, Contrib. Canadian Palaeontology, I, pt. 3, 1891, p. 208, pl. 28, figs. 2, 2*a*.

*Pycnosaccus canadensis*, Minchin *fide* Bather, Zoological Record, 1891, p. 82.

A very small species from the Mackenzie River basin of the Arctic region, in the strata which are said by Schuchert (Paleogeography of North America, p. 546), to be Middle Devonian. As stated by Bather in the Zoological Record for 1891 it belongs to this genus, but the specimen is insufficient for the determination of specific characters. It has small infrabasals.

*Type.* Museum Geological Survey of Canada.

*Horizon and locality.* Middle Devonian; Hay River, Mackenzie River basin, Canada.

### (?) **Pycnosaccus dubius** n. sp.

*Plate XIII, figs. 11a, b*

The peculiar crinoid figured under the above name was found in Decatur County, Tennessee, associated with *Pycnosaccus patei* and *Hormocrinus tennesseensis*. The size and general outline of the crushed crown are shown, but unfortunately the plates are so displaced that it is impossible to ascertain their arrangement above the radials. There are two small IBB visible as triangles at the side; very small BB, large RR—at least twice the size of BB—with two IBr, about two-thirds as wide as the RR. Whether iBr are present is doubtful; the form of the radial indicates the contrary, as there is a rather distinct curved facet with short shoulders, apparently rounded as usual in this genus. Nor can anything be ascertained about the anal side. There are no ridges or surface markings of any kind. One arm, well rounded, is intact in the upper part. The general shape and size of the confused mass of plates is about what we should expect for an average specimen of this genus or of *Hormocrinus*. The outline, figure 11*b*, shows the probable composition of the rays, and the relation of the basal and infrabasal plates.

The greatest peculiarity of this crinoid is its column, which is preserved entire; it is quite long, very wide at the proximal end, and tapers from there gradually to the extremity where it becomes very small, ending in a point and evidently not attached. From the calyx down for two-fifths of its length it is composed of uniformly short, slightly rounded columnals—the upper ones one-sixth as long as wide; these continue without alternation or change except that of decreasing width for the distance mentioned, where the diameter is reduced by one-half; here the columnals begin to lengthen and they increase rapidly from a length equal to one-half their width until at the distal end they are very elongate barrel-shaped, seven times longer than wide. This stem might be a variant of that of *Hormocrinus;* except in the remarkable taper it has some resemblance to that of the Carboniferous *Mespilocrinus*. The species might be of the type of *Mespilocrinus* minus the radianal, forming thus an intermediate step between that genus and *Nipterocrinus*. Until further discoveries its actual generic position must remain in doubt.

*Type.* Author's collection.

*Horizon and locality.* Silurian, Brownsport limestone, Beech River formation; Decatur County, Tennessee.

## **MESPILOCRINUS** De Koninck and Le Hon

*Plate V, figs. 1-24b*

*Mespilocrinus* De Koninck and Le Hon, Recherch. Crin. Carb. Belgique, 1854, p. 111 and text fig.—Pictet, Traité Palaeontologie, IV, 1857, p. 320.—Hall, Supplement Geol. Iowa, I, pt. 2, 1860, p. 69.—Bronn, Klassen u. Ord. Thier-Reichs, II, 1860, p. 231.—Schultze, Mon. Echinodermen Eifler Kalkes, 1867, p. 152, sep. (1866), p. 40.—Beyrich, Montasber. Akad. Wiss., Berlin, Feb., 1871, p. 46; Transl., Ann. and Mag. Nat. Hist., (4) VII, p. 403.—Von Zittel, Handbuch Palaeontology, I, 1879, p. 355; Grundzüge Palaeontologie, 1895, p. 138.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 41; *ibid.*, pt. 3, 1886, p. 144; Proc. Acad. Nat. Sci., Philadelphia, 1890, p. 388.—Miller and Gurley, Bull. 9, Illinois St. Mus., 1896, p. 39.—Zittel-Eastman, Text-book Palaeontology, I, 1896, p. 164; 2d Ed. 1913, p. 203.—Bather, Treatise on Zoology (Lankester), pt. 3, 1900, p. 188.—Springer, Amer. Geologist, XXX, 1902, p. 94; Jour. Geology, XIV, 1906, p. 517.—Young *Poteriocrinus*, Phillips, Geol. Yorkshire, II, 1836, p. 205.

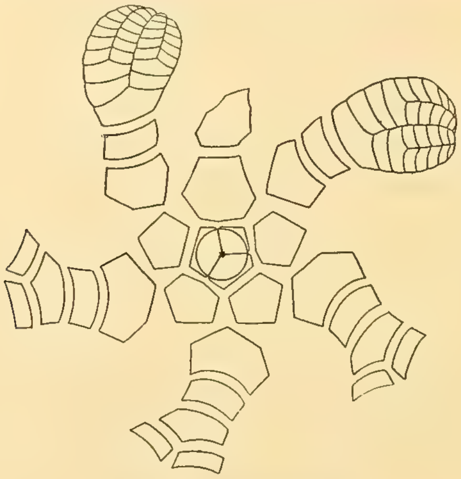

FIG. 20. *Mespilocrinus*

Lecanocrinidae with rays in contact except at anal side. Crown globose to ovoid. Infrabasals usually erect, extending beyond the column; exceptionally five in number. No radianal. Anal plates one or more, filling the interradius; no interbrachials in other areas. Primibrachs two. Rays usually abutting but not interlocking; often asymmetrical, with dextrorse twist. Arms dichotomous. Column not enlarging proximally; composed near the calyx of short columnals, becoming longer below; these vary in form from cylindrical with straight sides and no depression at the sutures, or simply convex or barrel-shaped with indented sutures, to greatly elongate, doubly conical, spindle-shaped segments, widest in the middle. The column is frequently curved so that the calyx hangs downward.

*Genotype. Mespilocrinus forbesianus* De Koninck and Le Hon.

*Distribution.* Lower part of Lower Carboniferous; Belgium, England and the United States.

*Mespilocrinus* is a *Lecanocrinus* minus the radianal—its legitimate successor in structure as well as time. Along with this modification there is a tendency to specialization, resulting in a lack of stability in some of the more important generic, and even larger, characters. It has somewhat the features of a degraded type; the crown is small in proportion to the stem, and instead of being erect often hangs downward, the upper part of the stem being curved or coiled so as to permit this. This is not a mere accidental position due to contraction at death, but while not accompanied by such an extreme modification as we find in *Calceocrinus,* it nevertheless represents a definite structure. The first few proximal columnals are cuneiform, and the adaptation of their shape to the curvature of the stem is perfectly shown in a side view of the coil (Pl. V, figs. 13*a, b*). With such a construction it does not seem possible that the crown could at any time have had an erect position. This feature is very prominent in *M. konincki,* but not so much so in *M. forbesianus.*

Along with this aberrant stem structure, there appears in this genus a very peculiar asymmetry in the disposition of the rays, by which they are bent to the right, so that instead of standing parallel to the vertical axis of the crown they tend to twist around it from left to right. As in the case of the stem, this feature is accompanied by a structural modification whereby the radials and lower brachials lose their symmetry of form; their lateral margins are of unequal lengths, their angles quite irregular, and their size unequal. These two characters do not always go together. In *M. konincki,* which seems to represent the extreme of specialization in this genus, both are conspicuous, and are also accompanied by a further striking modification of the stem in the development of spindle-shaped columnals of extraordinary length, some of them being ten times as long as their terminal diameter. *M. forbesianus* has the twisted and asymmetric rays, with a stem much less coiled and in other ways entirely different. *M. chapmani* has the drooping crown and partially coiled stem, with elongate but not spindle-shaped columnals; but it has not the asymmetry and twist of the rays.

With such instability of the characters that should distinguish genera, it is not surprising to find a further instability in one of the most strongly fixed characteristics of the whole group, viz., the three infrabasals, which prevail otherwise throughout the Flexibilia without exception save in the case of *Nipterocrinus* where they are coalesced. Here the infrabasals occasionally, and within the same extreme species, *M. konincki,* tend to revert to the fundamental five.

In addition to these erratic features there is also a tendency to variation in regard to the lateral contact of the rays. In at least one species, *M. thiemei,* the first primibrach does not fill the distal face of the radial, but leaves short shoulders on either side, while the arms are rounded, leaving small open spaces between them. Whether these spaces were occupied by small plates cannot be ascertained, but there is room for thinking this possible. Such a modification leads in the direction of a form like *Pycnosaccus,* and a species in which it was certainly developed would fill a place in the series as the Carboniferous representative of that genus freed from its radianal.

*Mespilocrinus* is characterized by an extraordinary enlargement of the posterior basal, which rises almost to the level of the distal face of the radials, filling part of the space occupied by the radianal and anal in *Lecanocrinus.* This feature is constant in all the species with the possible exception of *M. bordeni,* in which the anal side is unknown; it exhibits little variation, so that it is of no service in the separation of species. The genus is also remarkable for the frequent presence of only two secundibrachs. In one species, *M. konincki,* this is almost constant; in *M. forbesianus* the number varies from two to three; while in *M. bordeni* there are as many as seven—thus showing a rather unusual range of variation even in this somewhat variable character. The smaller number is also found in the latest species of *Taxocrinus, T. whitfieldi.* The surface in all species known is smooth.

Schultze, not understanding at that time the significance of the radianal, ranked this genus as a synonym under *Lecanocrinus.*

Miller and Gurley described a specimen of *M. konincki* from the Choteau limestone of Missouri (equivalent in part to the Lower Burlington) under the name of *Cyathocrinus* *blairi.* Miller afterward discovered its resemblance to *Mespilocrinus,* but refused to admit its identity because his specimen had five infrabasals. He happened to be short of names at that moment and therefore spared us the infliction of another generic synonym. The presence of the genus has been distinctly recognized from fragments in the Kinderhook beds of Fern Glen, Missouri, and it is represented by good specimens in the equivalent beds of Indiana and Kentucky.

De Koninck and Le Hon's species occurs in the lower limestone at Tournai, Belgium, substantially equivalent to the horizon of the Lower Burlington, or Choteau beds, as developed in Iowa and Missouri. Phillips figured under the name *"young Poteriocrinus"* a specimen from the English Mountain limestone which undoubtedly belongs to this genus, and probably to the type species. Phillips was not blind to its peculiarities, and figured it to show the arms in a rudimentary state. In America the genus does not occur later than the Burlington limestone.

*Mespilocrinus* is a very rare form, three of the species being represented by single specimens. I have tried for years without success to obtain a specimen of the Belgian species, only two having been found, to my knowledge, at Tournai since De Koninck's time; and in his large collection, acquired by Professor L. Agassiz for the Museum of Comparative Zoology, the species is not represented. Of the most characteristic species we have better material, but outside of the original Barris and Wachsmuth collections at Harvard, and my own, very few specimens are known.

The characters ordinarily available for the separation of species are not much differentiated in this genus, and we have to rely to some extent upon its erratic development in some of the broader characters, among which, however, I do not reckon that of the infrabasals, which I regard as purely individual.

The species may be arranged as follows:

### THE SPECIES OF MESPILOCRINUS

I. Arms in close contact.
- Rays asymmetric with dextrorse twist.
  - Specimens large, column regularly cylindrical.
    - Short columnals with straight sides.......................... *M. forbesianus.*
  - Specimens small, sutures not indented.
    - Crown turbinate, with large column facet.
      - Column large, composed of rounded columnals, changing from short proximally to very long and spindle-shaped...... *M. konincki.*
    - Crown globose, column facet small............................... *M. blairi.*
  - Sutures between Br beveled. IBr half as long as RR. IIBr 2 and 3..*M. romingeri.*
- Rays symmetric, without twist.
  - Specimens large. Sutures not indented.
    - Br very short and wide; IBr not over one-fourth length of R. IIBr 6 or 7.............................................. *M. bordeni.*

II. Arms not in close contact.
- Rays symmetric, without prominent twist.
  - Specimens small; crown ovoid, higher than wide; IBr nearly as high as RR................................................ *M. thiemei.*
  - Specimens large; crown subglobose.
    - IBr half as long as RR; columnars becoming elongate, but not spindle-shaped ........................................ *M. chapmani.*

### **Mespilocrinus forbesianus** De Koninck and Le Hon

*Plate V, figs. 1-3*

*Young Poteriocrinus* Phillips, Geol. Yorkshire, 1836, p. 205, pl. 4, figs. 5, 6.

*Mespilocrinus forbesianus* De Koninck and Le Hon, Recherch. Crin. Carb. Belgique, 1853, p. 112, pl. 2, figs. 1*a-c*.—Pictet, Traité Paleontologie, IV, 1857, p. 320, pl. 100, fig. 19.—Beyrich, Monatsber. Akad. Wiss. Berlin, Feb., 1871, p. 46 (Transl. in Ann. and Mag. Nat. Hist., (4) VII, p. 403.—Quenstedt, Petref. Deutschlands, IV, 1876, p. 516, pl. 108, fig. 28.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 42.—Springer, Jour. Geology, XIV, 1906, p. 523, pl. 7, fig. 14.

Type of the genus.

A large species. Crown subglobose, height and width about equal; spread of calyx from base to top of RR, 1 to 2.5; height to width at RR, 1 to 2. Base rounded. Surface smooth. Folded crown in maximum specimen, 14 mm. high by 14 mm. wide.

IBB small, visible in side view. BB large, post. B much the largest, reaching to full height of RR. Anal *x* short and broad, filling the interradius. RR somewhat unequal, and asymmetric; height of B to R to IBr, 4.2:3:1.7. IBr 2; IIBr 2 or 3; all Br relatively short and wide. Rays and arms broadly rounded, in close lateral contact, and twisting to the right as seen from the base; infolding soon after second bifurcation; the two posterior rays arching over the anal plate. Column large, cylindrical; proximal columnals short, slightly increasing downward, becoming uniform in size and shape as far as preserved.

The above description is to a considerable extent a repetition of generic characters. The proportionally large primibrachs distinguish the species from several others, and the column from all in which it is known. Here the column is a straight-sided cylinder, with no depressions at the sutures, nor bulging in the middle of the columnals which are relatively short; it represents the one extreme from which, with some gradations, we pass in other species to a column about as different as could possibly be imagined. The species is extremely rare in its original locality in Belgium. De Koninck had two specimens, and I know of only two that have been found since his time, one of them being the fine specimen with long stem in the British Museum (Pl. V, figs. 3*a, b*). This or a similar species occurs in England; the small specimen figured by Phillips as a young *Poteriocrinus* from the Mountain limestone of Yorkshire evidently belongs to the genus.

*Type.* De Koninck and Le Hon's original specimens are in the Royal Museum at Brussels. The other specimen here figured is in the British Museum.

*Horizon and locality.* Lower Carboniferous, Mountain limestone; Tournai, Belgium.

### **Mespilocrinus konincki** Hall

*Plate V, figs. 4-15*

*Mespilocrinus konincki* Hall, Supplement Geology of Iowa, I, 1860, p. 69; Bull. N. Y. St. Mus. Nat. Hist., I, 1872, Photo. Plates, pl. 6, fig. 9.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 42.

*Mespilocrinus scitulus* Hall, Jour. Bost. Soc. Nat. Hist., VII, 1861, p. 321 (Prelim. Notice, p. 9; Bull. N. Y. St. Mus. Nat. Hist., I, Photo. Plates, pl. 6, figs. 7, 8.

*Cyathocrinus blairi* Miller and Gurley, Bull. 7, Illinois St. Mus., 1895, p. 67, pl. 4, figs. 13, 14, 15, not figs. 11 and 12, nor *ibid.*, Bull. 8, p. 50, pl. 3, figs. 21, 22, nor *ibid.*, Bull. 9, p. 39.

A small species. Crown globose, height and width equal, widest about IAx; height to width there about 1 to 1.6. Base broad; spread of calyx from base to RR, about 1 to 2.5; cross-section circular. Surface smooth. Maximum crown, 8 mm. high by 8 mm. wide; average, 6 by 6 mm.

IBB of medium size. Post. B rising nearly to height of RR; other BB and RR about equal in height, and IBr about two-thirds as high; B to R to IBr, 2.5:2.4:1.5. RR evenly curved; succeeding plates broadly rounded. IIBr mostly 2. Anal *x* large, filling interradius. Rays in contact, infolding, closing below the third bifurcation; arms with marked dextrorse twist. Column large, composed near the calyx of short, uniform, rounded columnals, which gradually increase in length; from the fifteenth to twenty-fifth they become greatly elongated, widening in the middle and narrowing at the sutures until they become doubly conical, or spindle-shaped; the average proportions of a fully developed columnal of this kind are: length to width in middle, 2 to 1; to width at ends, 4 to 1.

This species was the first example of the genus recognized in America, Hall describing it from a very small specimen. It is from the Lower Burlington limestone, a horizon which in general faunal characteristics has much in common with the Mountain limestone of Belgium. It has always been a rare fossil at Burlington, but by good fortune I have been able to secure about a dozen excellent specimens, so that its peculiar characters can be thoroughly illustrated. The dextrorse twist of the arms is a very singular feature; looking at the specimen with the calyx erect, as we ordinarily do, the arms bend more or less to the right, some tending to pass under the adjoining ones. There is in connection with this a certain amount of irregularity in the form and size of the radial and brachial plates not usual in crinoids. The whole aspect of the crown is that of a rather irregularly rounded, somewhat asymmetric, globose cluster of short, thick arms. Along with this peculiarity there is the extraordinary stem, which in the extreme length of the median columnals is quite unique; and it usually tends to coil around the crown something after the fashion of *Herpetocrinus* and *Camptocrinus*. We can in practice always recognize the species from a small fragment of the stem or crown.

Compared with De Koninck and Le Hon's figures, it is not easy to distinguish this species from *M. forbesianus* by the crown alone. The general proportions and the relative dimensions of various plates are not very different, and the characteristic twist is equally prominent in both. Hall distinguished them easily in his description by the phrase which has since done duty at the birth of so many doubtful species: "This small species bears considerable resemblance to *M. forbesianus* of De Koninck and Le Hon, but differs much in the form and proportions of the plates." The average size of the specimens shows a constant difference, and the column, as shown by the British Museum specimen, is so different that in a less specialized form it would indicate a different genus. That of *M. forbesiocrinus* not only lacks the spindle-shaped median columnals, but is a perfectly even, straight-sided cylinder, without any depression at the sutures or notable increase in length of columnals.

As to Hall's other species, *M. scitulus,* I think there can be no question but that it is identical with this. It comes from the same bed in the Lower Burlington limestone at Burlington, and as a matter of practice I was never able to recognize any material difference among the specimens until I resurrected the type specimen of *M. scitulus* in the Museum of Comparative Zoology, where its identity had been lost (Pl. V, figs. 14*a, b*). Hall differentiated the second species on the greater angular prominence of the "basals" (IBB)—which were scarcely visible in his very small specimen of *M. konincki,* though well developed in others—and in the more rapid spreading of the calyx, which in his type specimen is due to foreshortening by vertical pressure. The difference in the infrabasals is, however, very remarkable, those of *M. scitulus* being not only more angular, but being distinctly five in number—a departure from the structure of the genus and of the group generally. Nevertheless I do not consider it in this case to be even a specific character.

For some unaccountable reason there is in this highly specialized form, with its dextrorse twist of arms and its strange column, a tendency in the infrabasal ring to revert to the fundamental five plates by division of the two larger ones. This happens in an irregular way. In the type of *M. scitulus* the plates are of unequal size. In Plate V, figure 11, the regularly shaped infrabasal disk is divided into five equal plates, while in another specimen the tendency to such division is to be seen, not developed into actual sutures, but visible by transmitted light in the semi-translucent calcite of the plates. In the specimens described by Miller and Gurley as *Cyathocrinus blairi* there are said to be five infrabasals, and in a specimen labeled as that species from the same locality, in the Gurley collection at the University of Chicago, only three are visible (Pl. V, fig. 18). This is simply a case where under the influence of strong specialization the bond even of ordinal characteristics becomes weakened, and the tendency to sporadic variation is increased. Miller, after describing his specimens as *Cyathocrinus,* noted the structural similarity to the Ichthyocrinidae, and afterwards discovered their apparent resemblance to *Mespilocrinus;* but on account of the difference in number of infrabasals he denied that they could belong to that genus, though in this case he considerately refrained from proposing a new genus for them. To be consistent, he would have had to establish a new family for the reception of certain specimens of a form which he could not have distinguished, even specifically, if the infrabasals were concealed—thus showing the absolute lack of that correlation of characters which is necessary to the validity of such divisions.

*Type.* The location of the type specimen is unknown. The figure is made from Professor Whitfield's drawing for Hall's photographic plates, together with a cast of the type made by Whitfield while it was in Hall's hands for description; this cast is in the American Museum of Natural History, New York.

*Horizon and locality.* Lower Carboniferous, Lower Burlington limestone and ranging rarely into the Upper Burlington; Burlington, Iowa.

### **Mespilocrinus blairi** (Miller and Gurley)

*Plate V, figs. 16-19*

*Cyathocrinus blairi* Miller and Gurley, Bull. 7, Illinois State Museum, 1895, p. 67, pl. 4, figs. 11, 12, not figs. 13-15; *ibid.*, Bull. 8, 1896, p. 50, pl. 3, figs. 21, 22; *ibid.*, Bull. 9, 1896, p. 39.—Miller, N. A. Geol. and Pal., Sec. Appendix, 1897, p. 741, fig. 1328.

Similar to *M. konincki,* except that the crown is globose instead of turbinate, the calyx broadly rounded below, the column facet smaller, and infrabasals more protuberant.

The small specimen figured under this name in Bulletin 7, of the Illinois State Museum, plate 4, figures 13-15, must be referred to *M. konincki,* having a broader base and straighter sides, and it is quite possible that the other specimens are simply more mature, and therefore more rotund, forms of the same species. All of Miller and Gurley's specimens are said to be from the Choteau beds at Sedalia, Missouri, but it must be remembered that the upper part of what is in Missouri called the " Choteau " is the same thing as the Lower Burlington beds in Iowa. In the Sampson collection made at the Sedalia locality, now in the University of Chicago, there are upward of 70 species of crinoids, and nearly all of them are well-known species long since described from Burlington. Miller and Gurley described a large number of new species from there, some of which are good, and some undoubted synonyms. Many of these forms have a wide geographical range. The exposure of Lower Burlington limestone which I explored on the eastern flank of the Rocky Mountains at Lake Valley, New Mexico—fifteen hundred miles from Burlington—yielded about 40 species of crinoids, nearly all of which are prominent and characteristic species at Burlington, such as *Dorycrinus unicornis, Cactocrinus proboscidialis,* etc., and the general fauna there is very similar to that of the Missouri Choteau.

Figure 21 on plate 3 of Bulletin 8, Illinois State Museum, represents two anal plates, but I doubt if this is correct; in the genus generally, and in other specimens from the same locality figured both by Miller and Gurley and herein, the posterior basal rises nearly or quite to the level of the radials, and this has probably been mistaken for a first anal. The figure of the summit is somewhat artificially composed, and there is another incorrect figure, 28, on the same plate.

*Types.* Miller and Gurley's types cannot be located, and I have copied their figures, which cannot always be relied upon for structural details; two of them appear to have five infrabasals. I also figure two specimens from the same locality from the Sampson collection, now in the University of Chicago, which show the usual three IBB.

*Horizon and locality.* Lower Carboniferous, Choteau (or Lower Burlington beds); Sedalia, Missouri.

### **Mespilocrinus romingeri** n. sp.

*Plate V, figs. 21a-d, 22*

A medium-sized species. Crown ovoid, 13 mm. high by 10 mm. wide, widest at IAx; height to width at top of RR, 1 to 1.5; spread of calyx from base to RR, 1 to 3.5; base broadly rounded.

IBB small; post. B very large; other BB and RR of about equal height; radial facets curved. IBr large, over half as high as RR, and nearly half as high as wide. IIBr 2 or 3. Rays in contact, with dextrorse twist, and plates asymmetric; rounded, short, and broad, infolding just beyond second bifurcation. Sutures between RR and IBr and succeeding plates beveled. Anal *x* small, filling the interradius. Column unknown, facet small.

This species when first recognized was represented by a single specimen, found by Dr. Carl Rominger in the Knobstone formation at Button Mould Knob, Bullitt County, Kentucky, and presented to me by him the year before his death; but it has been recently confirmed by another specimen from the same locality. It is a typical *Mespilocrinus,* with the unsymmetric and unequal radial and brachial plates, and twist of the rays. Except for its beveled sutures and smaller anal, which may be more apparent than real depending on the folding of the rays, this form would be difficult to separate from *M. konincki* if found in the same matrix at Burlington. From the other Knobstone species it is distinguished without difficulty, being of an altogether different type.

The species is dedicated to the memory of Dr. Carl Rominger, the veteran geologist and paleontologist of Michigan University, from whom I received the principal type specimen.

*Types.* Author's collection.

*Horizon and locality.* Lower Carboniferous, Knobstone Group; Button Mould Knob, Kentucky.

### **Mespilocrinus bordeni** n. sp.

*Plate V, figs. 23a-c*

A large species. Crown subovoid, broadly rounded above, narrower below; 20 mm. high by 20 mm. wide; widest to top of RR, where height to width is 1 to 1.5; spread of calyx from base to top of RR, 1 to 3; base small.

IBB small. BB large. RR large with facets straight. IBr 2, very short and wide, less than one-fourth the length of radials, and one-fourth as long as wide. B to R to IBr, 9:7:1.5. IIBr 6 or 7, very short, decreasing rapidly in width upward. Rays and arms flat, in close contact, infolding about the second bifurcation. Column large proximally, facet almost as large as IBB; unknown farther down. Anal side unknown.

The distorted specimen upon which this species is founded was given to me by the late Professor W. W. Borden, who personally collected it during his later years from the Knobstone beds at one of the knobs near Borden, Clark Co., Indiana. It was associated with some other rare crinoids, among them *Wachsmuthicrinus spinosulus,* from thin layers of clay, and all much flattened. Part of the crown is broken away, unfortunately including the anal side. Three of the rays and the base are in good condition, and from these I have made an accurate restoration, showing the undistorted form and correct proportions of the specimen (Pl. V, fig. 23*c*).

This species is in some respects very different from any of the others, and it is quite possible that if the anal side were known it would fall into another genus. The extremely short and wide interlocking brachials, and the unusual number of secundibrachs, give to it a facies quite peculiar. In other species the secundibrachs are generally two, with sometimes three, whereas the six or seven found here would be extraordinary even for *Lecanocrinus,* which the short brachials recall. These differences of course do not of themselves indicate another genus, but they induce a strong desire to see a complete specimen. This form apparently lacks the asymmetry and dextrorse twist of the rays characteristic of typical species. The genus is represented in the same beds by another species which is not at all like this.

The specific name is in memory of Professor W. W. Borden, of Borden, Indiana; a pioneer geologist, who died in December, 1906, at the advanced age of 80 years. An ardent lover of Nature, and a zealous collector until the last, he was in his personal relations and friendships a most lovable man. To his sympathetic kindness I am indebted for a number of unique specimens, which he hoped might be of use to Science in my hands.

*Type.* Author's collection.

*Horizon and locality.* Lower Carboniferous, Knobstone Group; Clark County, Indiana.

### **Mespilocrinus thiemei** n. sp.

*Plate V, figs. 20a, b*

A small species. Crown elongate ovoid, subpentangular; 9.5 mm. high by 7 mm. wide, widest about IAx; spread of calyx from base to top of RR, 1 to 3; height to width, 1 to 1.5; base rounded.

IBB small. Post. B very large, rising nearly to level of RR. Height of B to R to IBr, 2.7:2.2:2. Radial facets strongly curved, not filling distal face of RR. IBr and higher brachials relatively narrow, height to width about 1.6 to 2; rounded and not in close contact laterally. IIBr mostly 3, with another bifurcation visible. RR and Br symmetric, and rays not twisted. Anal *x* very short, not filling interradius, and probably followed by others or by perisome. Column small, round; proximal columnals for several joints very short, with convex sides, gradually increasing in length so far as preserved.

The unique specimen upon which this species is founded was in a collection made by Dr. Otto Thieme, one of the pioneer collectors of Burlington, and acquired by me in 1870. It has rested in the tray along with other *Mespilocrini* ever since, with a strong " ? " upon the label. In all the other contemporary collections of Barris, White, Wachsmuth and myself, and those made in nearly 40 years following, no other specimen of it has appeared. It departs from the typical form of the genus in the fact that the first primibrachs do not fill the full width of the radial, but there is left at each side of the deeply curved radial facet a short shoulder, apparently unoccupied. Hence the rays are not in contact, but small open spaces are left between them. The specimen is very well preserved in a fine-grained matrix easily removed and favorable to the preservation of minute structures; but I have been unable to detect any trace of small plates in these interbrachial spaces. In this respect it is somewhat in the condition of the aberrant species described under *Lecanocrinus,* now referred by me to *Asaphocrinus;* but the parallel does not continue further, for the anal plate, although quite different from that of the typical species, does not vary in the direction of the tube-like series of the Taxocrinidae. This short and wide plate is decidedly straight above, and was undoubtedly followed by others, but whether solid plates or an integument of small ones, as in *Pycnosaccus,* cannot be ascertained. The latter is the more probable, because if there had been a solid plate filling the arch of the posterior rays, as in the genus generally, there is no reason why it should have disappeared; whereas the integument of small plates is a most fragile structure, and in forms like this usually falls to pieces and is lost. If the latter were the case, and as would undoubtedly follow the regular interbrachial spaces were also occupied by small plates, this would constitute a perfectly good genus holding the same relation to *Mespilocrinus* that *Pycnosaccus* does to *Lecanocrinus,*—in other words, the Carboniferous successor of *Pycnosaccus.* When we remember that in over 50 years' collecting at Burlington only a single specimen was ever found showing the true interbrachial structure of *Nipterocrinus,* and that it is only now after the lapse of 30 years since Angelin described *Pycnosaccus* that the actual structure of the same parts in that genus is made known, it need not be thought strange that the same fact as to this extremely rare form should still be open to conjecture.

The weight of evidence in this species is in my opinion rather in favor of a plated integument in the upper part of the anal interradius; but what makes me hesitate to affirm it as to the other areas is the fact that they are so narrow and the shoulders of the radial for their support so short. In *Pycnosaccus,* after seeing the first specimen in the British Museum, I never had any doubt that it had this structure, because the spaces for lodging the interbrachial perisome were so wide and prominent, and I had in mind the unpublished case of *Nipterocrinus* so closely analogous to it. But in this case I do not feel warranted in proposing a new genus where the basic fact is unproved, and I therefore prefer to treat this and the next species as variant forms of the genus. The dextrorse twist of the arms and somewhat irregular contour of plates, so characteristic of some species, are wanting in this; the apparent bending to the right of the middle ray in figure 20*a,* Plate V, is accidental, not structural. Although the stem is not preserved far enough to show it positively, I suspect that it had merely elongate, cylindrical columnals, like that of *M. chapmani.*

Dedicated to the memory of Dr. Otto Thieme, who was among the first to appreciate the wealth of the crinoidal fauna of the Burlington rocks.

*Type.* Author's collection.

*Horizon and locality.* Lower Carboniferous, Lower Burlington limestone. The specimen came from a locality famous among the early Burlington collectors, known as "Patterson Hollow," which produced many of the finest crinoids from the lower bed. They occurred in a layer of rather soft, very even-grained buff limestone, and were of a light, creamy color, easily cleaned from the matrix; and many of them being of delicately ornamented species, they were justly esteemed the most beautiful fossil crinoids ever found. The Barris collection, and the original collection of Wachsmuth, both now in the Museum of Comparative Zoology at Harvard, contain some of the finest of that material. Like nearly all the other choice localities at Burlington, it has by the growth of the city become covered by buildings, and thus lost to the fossil hunter.

### **Mespilocrinus chapmani** n. sp.

*Plate V, figs. 24a, b*

A large species. Crown subglobose, narrowest below; subpentagonal; 17 mm. high by 17 mm. wide, widest at IIBr; spread of calyx from base to RR, 1 to 2.5; height to width at RR, 1 to 1.6.

IBB small. Post. B rising about to height of RR. Height of B to R to IBr, 4.5:4:2.5. RR convex, facets strongly curved. IBr and higher brachials rounded and not in close contact laterally. IIBr mostly 2. Anal *x* large, filling the interradius. Column large; proximal columnals short, increasing gradually to fairly long, barrel-shaped columnals, not doubly conical, measuring 4 mm. long by 3 mm. wide.

This species, like its predecessor, is founded upon a solitary specimen discovered in the City of Burlington in 1906; it is the only one belonging to the genus ever found in the Upper Burlington limestone, with the possible exception of a small specimen *M. konincki*—thought to be from that horizon. It is of a similar aberrant form to *M. thiemei,* but the anal side has strictly the structure of the genus. The specimen is flattened, and the interbrachial spaces cannot be seen to their full extent; but from what is visible, and the strong rounding of the rays, it is evident that the lateral contact prevailing in the genus generally is lacking here. Enough of the column is preserved to show that it does not pass into the extremely long, doubly conical columnals of *M. konincki;* they are elongate, but simply barrel-shaped, with convex sides and beveled edges. In order to show the actual proportions of this unique specimen, I have given a restoration of the crown from careful measurements of the parts visible, figure 24*b*.

The name of this species is given in honor of Mr. Kenneth M. Chapman, of Santa Fé, New Mexico, the artist to whose great skill is due the majority of the fine illustrations accompanying this work.

*Type.* Author's collection.

*Horizon and locality.* Lower Carboniferous, Upper Burlington limestone; Burlington, Iowa.

## **NIPTEROCRINUS** Wachsmuth

*Plate XV*

*Nipterocrinus* Wachsmuth in Meek and Worthen, Proc. Acad. Nat. Sci., Philadelphia, Dec., 1868, p. 341.—Meek and Worthen, Geol. Surv., Illinois, V, 1873, p. 434.—Von Zittel, Handbuch Palaeontologie, I, 1879, p. 352.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 55; *ibid.*, pt. 3, 1886, pp. 145, 188.—Miller, N. A., Geology and Palaeontology, 1889, p. 262.—Bather, Treatise on Zoology (Lankester), pt. 3, 1900, p. 188.—Springer, Amer. Geologist, XXX, 1902, p. 95; Jour. Geology, XIV, 1906, p. 519.—Zittel-Eastman, Textbook Paleontology, 2d Ed., 1913, p. 204.

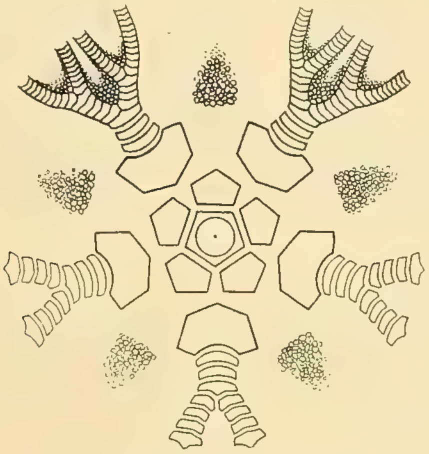

FIG. 21. *Nipterocrinus*

Lecanocrinidae with rays above radials separated by perisome only. Crown elongate; calyx well differentiated. Infrabasals large, forming part of calyx wall, apparently fused into a discoidal plate. No radianal or anal plates. Interbrachial areas wide, occupied by perisome passing into the tegmen. Primibrachs three (or four). Radial facets not filling distal face of radials. Arms dichotomous, divergent. Column large, long, cylindrical, not (or but slightly) enlarging at the calyx; with radicular cirri or branches at distal end.

*Genotype. Nipterocrinus wachsmuthi* Meek and Worthen.

*Distribution.* Lower Carboniferous, Burlington limestone; United States.

This genus may be called the Carboniferous successor of *Pycnosaccus,* having a well-differentiated calyx with both radianal and anal plates eliminated. The general habitus—with large radials and narrow brachials, without regular interbrachials but the spaces filled by perisome—is identical with that of the Silurian genus, and the superficial resemblance is also very striking, especially to forms like *Pycnosaccus welleri* (Pl. XIII, figs. 3-5). The three or more primibrachs, which in that species are exceptional for the genus, are the rule in *Nipterocrinus.* The first primibrach is relatively small and narrow, resting in a deeply excavated sinus or radial facet, giving to the rays a very different aspect from those of the Flexibilia generally; and in this respect, especially in the imperfect condition in which specimens are usually found, the genus much resembles *Cyathocrinus.* The presence of the strongly sinuous sutures between the brachials is what first suggested to Wachsmuth the doubt that this rare form could belong to that genus. In two other features, however, besides the anal structures, there is a decided morphological difference between this genus and *Pycnosaccus.*

(1) The column: this, while cylindrical in both and without any marked enlargement next to the calyx, has in *Nipterocrinus* proximally very thin knife-edged columnals, which gradually increase in length downward until they become longer than wide, but without any alternation in length or width, thus making the stem smooth throughout; whereas in *Pycnosaccus* the entire stem, so far as known, is composed of large convex columnals with one or more short and inconspicuous ones interpolated. These features in *Nipterocrinus* are well shown by the fine specimen figured on Plate XV, figure 5, with a complete stem which has plain traces of radicular cirri and a branched root.

(2) The base: the infrabasals are confined to a low undivided disk, differing therein not only from *Pycnosaccus* but from all other crinoids of this order, this being the only genus except *Mespilocrinus* to show any departure from the normal division of infrabasals into three plates. This structure has not hitherto been understood. Meek and Worthen, in describing the genus (Proc. Acad. Nat. Sci., Philadelphia, vol. 20, p. 341), supposed it had five infrabasals, while Wachsmuth and Springer (Rev. Pal., pt. 1, p. 55) were inclined to think it had three; but neither undertook to give the number with certainty, as the few specimens then known did not show it. Two specimens since obtained (Pl. XV, figs. 4, 10*d*) prove the actual construction beyond a doubt, especially figure 4, in which the infrabasal disk is isolated and shown to be perfectly solid.

The systematic position of *Nipterocrinus* was at first a matter of doubt. Its great superficial resemblance to *Cyathocrinus* scarcely left room for a suspicion that it could belong to a group of which the utterly different *Ichthyocrinus* was the type, and it was accordingly thought by Wachsmuth and by Meek and Worthen to be probably allied to the former genus, although the sinuous sutures in the rays did not escape their attention, and led them to suggest the resemblance in this respect to *Taxocrinus* and allied forms. As the peculiar characters of the present group came to be better appreciated, it was seen that the last mentioned structure was of more weight than the superficial resemblance, and it is a striking example of Wachsmuth's great sagacity in the interpretation of fossil crinoids, that he inferred the necessary presence of an integument of interradial plates connecting the lower brachials by reason of which it was ranged under the Ichthyocrinidae by Wachsmuth and Springer in 1879.

This supposition was without direct evidence at the time, for the unique specimen figured on Plate XV, figures 10*a-d*, by which it is now fully confirmed, had not then been discovered. This specimen, which is the only one ever found preserving these structures in perfect condition, shows the small plates completely filling the interbrachial spaces to the third order, and leaves no doubt as to the true relations of the genus. It is rather remarkable that in so small a specimen the perisome should appear so far up the arms, indicating an unusually high tegmen, but this is actually the case; the preservation is so perfect on one side of the specimen that the perisome can be plainly seen firmly soldered to the sides of the arms to the height shown in the figure. Just how the integument rests upon the shoulders of the radials is finely shown in figure 10*c* from an interradius where the small parts are partly broken away. I have also found traces of these small plates in two other specimens.

*Nipterocrinus* has been ignored by Quenstedt, and by Von Zittel in the Grundzüge, owing no doubt to the element of uncertainty in the descriptions of its structure, now dispelled by the discovery of new material. The stratigraphic range of the genus is limited to the two divisions of the Burlington limestone and the lowest part of the Keokuk; it has not been found outside the vicinity of Burlington, Iowa, where it is one of the rarest fossils. Only two species have been certainly recognized, as follows:

## THE SPECIES OF NIPTEROCRINUS

I. Arms relatively long.
  IIBr 6 to 9. IIIBr 10 to 15 or more.............................. *N. wachsmuthi.*
II. Arms relatively short and strong.
  IIBr 4 or 5. IIIBr 6 or 7........................................ *N. arboreus.*

### **Nipterocrinus arboreus** Worthen

*Plate XV, figs. 9-10*

*Nipterocrinus arboreus* Worthen, Geol. Surv. Illinois, V, 1873, p. 436, pl. 4, fig. 8.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 56.

This Lower Burlington representative of the genus is similar to the type species, so far as can be ascertained from the specimens, in everything except the number of brachials beyond the first, the IIBr being 4 or 5, and IIIBr 6 or 7. This character is constant in two very well-marked specimens; and it makes the rays appear more robust, the brachials being relatively shorter and wider. The stem is unknown beyond a few proximal joints. There was nothing in Worthen's description to differentiate this species from the type, and the above grounds, not mentioned by him, are the only ones upon which their separation may be maintained.

*Types.* Worthen's original is in the University of Illinois; that of figure 10 in the author's collection.

*Horizon and locality.* Lower Carboniferous, Lower Burlington limestone; Burlington, Iowa.

### **Nipterocrinus wachsmuthi** Meek and Worthen

*Plate XV, figs. 1-8*

*Nipterocrinus wachsmuthi* Meek and Worthen, Proc. Acad. Nat. Sci., Philadelphia, 1868, p. 342; Geol. Surv. Illinois, V, 1873, p. 435, pl. 2, fig. 4.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 56.—Springer, Jour. Geology, XIV, 1906, p. 522, pl. 6, fig. 18.

Type of the genus.

A medium-sized species. Crown elongate. Calyx low, hemispheric, evenly curved; height to width at top of RR, about 1 to 1.55; spread of calyx from column facet, 1 to 3; side outline convex; cross-section circular. Surface smooth or finely granular, without ridges or angularities. Crown of large specimen, 45 mm. high by 22 mm. wide.

IBB low and flat, barely visible in side view; undivided. BB narrow, nearly as high as RR, but not appearing so in a side view because foreshortened. RR by far the largest plates of the calyx, and much wider than high; facets narrow, about half the width of R, deeply curved, leaving rounded shoulders at either side for attachment of perisome. IBr 3 or 4; IIBr 8 or 9; IIIBr 10 to 15 or more, with another bifurcation only on the inner ramus of the dichotom. Arms rounded and deep, with strongly curved sinuous sutures. Column very long, large in proportion to the crown, not expanding proximally, and with scarcely any taper until near the end where a few radicular cirri or branches appear; proximal columnals extremely thin, equal, with straight sides; about one-twelfth as long as wide, gradually increasing in length without any alternation, until the distal columnals become longer than wide.

This species, the more elongate form of the genus, belongs to the Upper Burlington limestone. One imperfect specimen, considerably larger than any others but otherwise scarcely distinguishable from this, has been found in the lower passage beds of the Keokuk limestone. In one specimen (fig. 2), exceptionally, the primibrachs are increased from their normal number to four. The succeeding intervals between the bifurcations are very long, and this constitutes the best distinction from the Lower Burlington species; only in one specimen, apparently intermediate in character, do they fall as low as six brachials, those of this order being usually eight or nine, and the IIIBr rarely less than 14.

*Types.* The original of figure 1 is in the Museum of Comparative Zoology, Harvard College. The other figured specimens are in the author's collection.

*Horizon and locality.* Lower Carboniferous, Upper Burlington limestone; Burlington, Iowa.

## Family SAGENOCRINIDAE Roemer, emend. Springer

SAGENOCRINOIDEA WITH INFRABASALS MORE OR LESS RECUMBENT, TAKING LITTLE PART IN THE CALYX WALL. CROWN USUALLY ELONGATE. RAYS ABOVE RADIALS PARTLY OR WHOLLY SEPARATED

### Analysis of the Genera

- I. *RA in form of R; under r. post. R.*
  - Anals and iBr chiefly in lower part of areas, followed by perisome.
    - Arms dichotomous.
    - Anals more than one abreast. IBr 2............................TEMNOCRINUS.
    - Anal *x* followed by others in series tending to form a tube. IBr 3..MERISTOCRINUS.
- II. *RA obliquely to left of r. post. R, not touching r. ant. R, usually between BB.*
  - Anal and iBr areas filled with solid plates in more than one series.
    - Arms dichotomous. IBr 2..................................SAGENOCRINUS.
- III. *RA only in upper oblique position.*
  - Anals and iBr well developed in lower part of areas, passing into perisome. IBr 2 ...........................................LITHOCRINUS.
    - Arms heterotomous. 10 main trunks with ramules.
  - Anals and iBr variable; may be only a few in lower part, followed by perisome, or numerous, filling areas with solid plates.
    - Arms dichotomous.
      - Post. B longer than others. IBr 3 (exceptionally 2).........FORBESIOCRINUS.

This family partakes in a smaller degree of the infrabasal character of the Lecanocrinidae—those plates, while taking a small part in the calyx wall, being to a variable degree recumbent, and reaching the outer surface by a rather narrow rim or wedge-form extension from the interior. It is in general characterized by a large, elongate and spreading crown, with rays not in contact, and with arms more or less divergent. Only in young specimens of *Forbesiocrinus* is there any suggestion of the rotund crown of the Lecanocrinidae, and none of the genera have the closely abutting or interlocking rays and arms which are found to a considerable extent in both the other families of this suborder. Anal structures in some form exist throughout, including radianal of the primitive and oblique types. *Meristocrinus* is aberrant in its characters, tending toward the Taxocrinidae in its anal structure.

Four of the five genera are Silurian, and while represented as late as the middle of the Lower Carboniferous by the vigorous and widely distributed *Forbesiocrinus,* the line of succession of this family through the Devonian is yet to be discovered. One genus, *Temnocrinus,* is restricted to England, *Lithocrinus* to Gotland, *Meristocrinus* to these two areas; while the other two, *Sagenocrinus* and *Forbesiocrinus,* are common to both Europe and America.

The name Sagenocrinidae was first used by Roemer in Bronn's Lethaea Geognostica, 1852-54, p. 228, to include a single genus, *Sagenocrinus,* without any hint of relationship to a larger group; and the genus was not at first included in the present group by Wachsmuth and Springer.

*Geological and Geographical Distribution*

**Number of known species**

(Open figures indicate American, those marked ( ) European)

| Formation | | | Sagenocrinidae | | | | | |
|---|---|---|---|---|---|---|---|---|
| General | American | Approximate European Equivalents | Temnocrinus | Meristocrinus | Sagenocrinus | Lithocrinus | Forbesiocrinus | Total |
| L. Carboniferous | Warsaw | ... | ... | ... | ... | ... | 2 | |
| | Keokuk | ... | ... | ... | ... | ... | 4 | |
| | Burlington | Mountain limestone | ... | ... | ... | ... | 2<br>(1) | |
| | Kinderhook-Waverly | | ... | ... | ... | ... | 1 | 10 |
| Devonian | | | | | | | | |
| Silurian | Niagaran | Wenlock | ...<br>(1) | ...<br>(5) | 2<br>(1) | ...<br>(1) | ... | 10 |
| | American species | 11 | ... | ... | 2 | ... | 9 | |
| | European species | (9) | (1) | (5) | (1) | (1) | (1) | |
| | Total species | 20 | 1 | 5 | 3 | 1 | 10 | 20 |

## **TEMNOCRINUS** Springer

*Plate XVI*

*Temnocrinus* Springer, Amer. Geologist, XXX, 1902, p. 94; Jour. Geology, XIV, 1906, p. 518.—Zittel-Eastman, Textbook Paleontology, 1913, p. 204.
*Cyathocrinites,* Miller (in part), Nat. Hist. Crinoidea, 1821, p. 88.
*Isocrinus,* Phillips (in part), Pal. Fossils Cornwall, 1841, p. 30.
*Cladocrinites,* Austin (in part), Ann. and Mag. Nat. Hist., XI, 1843, p. 197.
*Cupulocrinus,* D'Orbigny (in part), Prodrome Pal. Strat., I, 1849, p. 46.
*Taxocrinus,* Wachsmuth and Springer (in part), Revision Palaeocrinoidea, I, 1879, p. 49.
*Cyathocrinus,* Roemer in Bronn (in part), Lethaea Geognostica, I, 1852-54, p. 236.

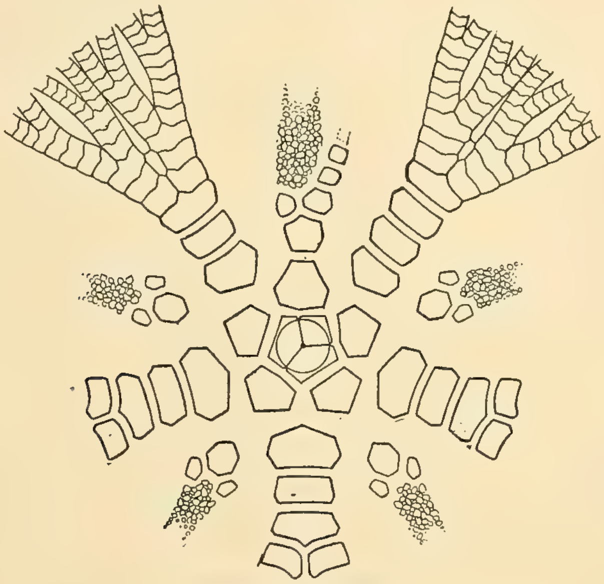

Fig. 22. *Temnocrinus*

Sagenocrinidae with rays above radials separated by solid plates in lower part of areas. Crown elongate, expanding upward. Infrabasals recumbent, taking small part in calyx wall. Radianal in primitive position in form of radial directly under right posterior ray. Anal *x* and few smaller plates filling only lower part of area. Interbrachials few, followed by perisome passing into the tegmen. Primibrachs two. Arms dichotomous, divergent. Column with proximal enlargement.

*Genotype. Cyathocrinites tuberculatus* Miller.

*Distribution.* Silurian; England.

This genus was founded upon a species which has been more frequently cited, figured, and discussed than any other species of the group, often as the chief representative of *Taxocrinus,* if not the actual type. As is more fully shown in the discussion under that genus, Phillips did not designate any type species, but there are good reasons for considering that the genotype was one of the species which he himself described, and not Miller's *Cyathocrinites tuberculatus* which he associated with them in his proposed generic group. Miller's species differs from the others in the presence of a radianal under the right posterior ray, and of two primibrachs in the other rays instead of three; and still more markedly in the construction of the anal area, which is filled in the lower part by solid plates suturally united with the adjacent rays. This last character differentiates it from *Taxocrinus* upon grounds of family rank.

It was in this species that I first[1] observed the peculiarity in the right posterior ray which has been found to cut an important figure in the classification and phylogenetic history of the whole group, viz., an arrangement suggesting the presence of an extra primibrach, *i. e.*, a radial followed by three primary plates in the series, instead of two as in all the other rays. This appearance is caused by the fact that the two lower plates in this ray are the representatives of a compound radial transversely divided, the lower half being a radianal, located in its primitive position as an infer-radial, resting upon the basals, and directly under the super-radial as in the Inadunate genus *Dendrocrinus*. It is in the direct median line of the ray, in contact with the radial next toward the right, and having the shape and almost the size of the radials in other rays. This fact was not indicated by the principal published figures of *Cyathocrinus tuberculatus*, upon which we had previously relied for an understanding of its characters. Neither Miller's original figure (Nat. Hist. Crin., 1821, p. 88) which was copied by Schlotheim, nor Goldfuss's Figure A (Petref. Germ., 1826, taf. 58) which was copied by Pictet, show anything of it; nor does Phillips's figure of another specimen in Murchison's Silurian System, plate 18, nor Roemer's of still another in Bronn's Lethaea Geognostica, taf. 4, figure 16. None of these but Goldfuss's shows the posterior side. Quenstedt (Handb. Petref., 1885, taf. 75) copied both Goldfuss's and Roemer's figures, but in addition gave an original figure (11) of the posterior side of another specimen from Dudley, in which the extra plate in the right posterior ray is plainly seen. It appears in the figure to be on the left side, but this is due to the reversal of the drawing in printing. Out of 19 specimens in my own collection showing the posterior side, and 15 in the British Museum, only one has two primibrachs in each ray, while all the others have the primitive radianal. Upon the evidence it cannot be doubted that this is a fixed and constant structure, and on this ground I proposed in 1902 to separate the species *tuberculatus* from *Taxocrinus* under the present generic name *Temnocrinus*.

Several of the published figures show the presence of a good-sized interbrachial plate, but it has not been known until now that these plates, either directly or after another range of smaller plates intervening, are succeeded by a plated integument of small irregular pieces passing from them, and sometimes from intersecundibrachs also, into the perisome of the tegmen. This structure appears very plainly in several of my specimens, and is perfectly shown in the beautifully preserved example illustrated by figure 5 on Plate XVI. The anal side is similarly constructed, but has a greater number of larger solid plates filling the lower part of the area, and shows a tendency to develop a series adhering to the right posterior ray.

This genus is one of the few occurring at Dudley which has not been found either in Gotland or America. It is represented exclusively by the type species, the only modification being due to variations in the marginal nodes of the brachial plates in a few specimens, and in the degree of the tubercular ornamentation, none of which are sufficiently constant to mark a different species.

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[1] American Geologist, vol. 30, 1902, p. 94.

### **Temnocrinus tuberculatus** (Miller)

*Plate XVI, figs. 1-15*

*Cyathocrinites tuberculatus* Miller, Nat. Hist. Crinoidea, 1821, p. 88, fig. 1 (not fig. 2 = *Ichthyocrinus*).—Goldfuss, Petrefacta Germaniae, 1833, p. 190, pl. 58, fig. 6A.—Phillips in Murchison, Silurian System, 1839, p. 671, pl. 18, figs. 6, 7.—Austin and Austin, Mon. Recent and Fossil Crinoidea, 1843-49, p. 66.

*Cyathocrinus tuberculatus,* Agassiz, Mem. Soc. Neuchatel, I, 1836, p. 197.—Quenstedt, Handbuch Petrefactenkunde, Ed. 1, 1852, p. 617; 3d Ed., 1885, p. 944, pl. 75, figs. 8-11; Petrefaktenkunde Deutschlands, IV, 1876, p. 500, pl. 107, fig. 134.—Roemer in Bronn, Lethaea Geognostica, I, 1852-4, p. 236, taf. IV, figs. 16*a, b*.—Murchison, Siluria, 1859, p. 246.

*Isocrinus tuberculatus,* Phillips, Palaeozoic Fossils of Cornwall, 1841, p. 30. (*Isocrinites*) Austin and Austin, Ann. and Mag. Nat. Hist. (1) X, 1842, p. 108.

*Cladocrinites tuberculatus,* Austin and Austin, Ann. and Mag. Nat. Hist., (1)XI, 1843, p. 197.

*Taxocrinus tuberculatus,* Phillips in Morris, Cat. British Fossils, Ed. 1, 1843, p. 59; 2d Ed., 1854, p. 90.—M'Coy (Sedgwick & M'Coy) British Palaeozoic Fossils, 1854, p. 53.—Phillips in Murchison, Siluria, 1859, pp. xx, 246, 536, pl. 14, figs. 5, 6.—Pictet, Traité Paléontologie, 2d Ed., IV, 1857, p. 327, pl. 101, fig. 10.—Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1865, p. 141; Geol. Surv. Illinois, II, 1866, p. 270.—Schultze, Mon. Echinodermen Eifler Kalkes, 1867, p. 145, Sep. (1866), p. 33.—Baily, Fig. and Desc. British Pal. Fossils, 1875, pl. 18, fig. 2.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 49.—Bather, Ann. and Mag. Nat. Hist. (6) IX, 1892, p. 202.

*Cupulocrinus tuberculatus,* D'Orbigny, Prodrome Pal. Stratigraphique, I, 1849, p. 46.

*Dimerocrinites tuberculatus,* Pacht, Gattung *Dimerocr.,* 1852, p. 8.

*Temnocrinus tuberculatus,* Springer, American Geologist, XXX, 1902, pp. 92-94.—Jour. Geology, XIV, 1906, pl. 7, fig. 15.

*Encrinites armatus,* Schlotheim, Nachtrage Petrefaktenkunde, 1823, p. 98, pl. 26, fig. 7*a;* Merkwurdige Versteinerungen, 1832, p. 25.

Type of the genus.

A moderately large species. Crown elongate, widest about $IIIBr_3$, where height to width is about 1 to 1.1; spread of calyx, 1 to 3. Rays and their divisions strongly rounded, and iBr areas deeply depressed; sutures more or less sinuous, slightly beveled, and not imbricated. Surface ornamented by small raised tubercles in horizontal rows on radials and lower brachials, tending to become confluent and form parallel vertical ridges on higher brachials, with median longitudinal ridges on interbrachials almost smooth in some specimens. Height of a large crown, 40 mm., width, 20 mm.; of base, 6.5 mm.

IBB visible as low pentagons. BB smaller than RR; post. B truncate, followed by a large anal plate usually angular and supporting a second range of two, succeeded by a diminishing series of 2 to 4 others most numerous at the right side, where they are suturally connected with the ray. RA large, in form of a radial directly under and forming the base of the right posterior ray, connecting with radial of next ray to the right. iBr large, elongate, usually with a median longitudinal ridge, and followed by two small plates abreast at the upper corners, sometimes not connecting in the middle; these as well as the anal plates are directly followed by finely plated perisome, occupying the areas to about the height of the second bifurcation, and passing into the tegmen; a single iIIBr often present. IIBr 3, exceptionally 2 or 4; IIIBr 4 or 5 inner and 7 to 9 outer, with usually one bifurcation beyond and still another in very mature specimens; lateral margins of brachials rounded, or angular at the edge, often projecting as sharp nodes which sometimes tend to form prominent, wing-like buttresses along the margin of the rays and their divisions. Arms rounded and deep, the distal divisions tapering rapidly and coiling inward over the tegmen to fine points. Tegmen at a level a little above the last IIBr consisting of finely plated calcified perisome, which passes down between the rays to a connection with iBr plates. Column large, about as wide as the IBB ring; tapering from the calyx for about a dozen diminishing columnals of equal thickness, there being 12 in a length of 7 mm. in a large specimen; from there the alternate columnals begin to increase in length, and at a distance of 65 mm. are more than twice as long as those interposed; the column gradually diminishes in thickness to an unknown length and probably ends in one or more slender roots.

Miller figured under the name, *Cyathocrinites tuberculatus,* two specimens, of which his figure 2 is the distal part of an *Ichthyocrinus pyriformis.* His figure 1 is a composite affair, constructed from the calyx and arms of a specimen of this species with the stem of *Sagenocrinus* added for greater completeness (Pl. XVI, fig. 1). I have a dozen specimens showing more or less of the stem, and in none of them is it of the form shown by Miller's figure. The species is exceedingly well marked, and when once understood is readily identified.

The surface ornament is very characteristic, and need not be mistaken for that of any other form in the Wenlock beds; the tubercles of *Ichthyocrinus pyriformis* are much finer. There is considerable variation in the intensity of the ornamentation, some specimens appearing almost smooth; this, however, is largely a matter of preservation. Looking at such a specimen as figure 15, Plate XVI, with its widely-projecting wings or buttresses along the margins of the rays, one would be inclined to think it a different species from most of those on the same plate; but the fact is that the same thing is found to a greater or less degree in most of the specimens. Small angles or rounded nodes project in various sizes from the lateral margins of the brachials just exterior to the line where the perisome joins them, but usually these are not seen in an ordinary view on account of the depth of the plates. Figure 15 is flattened somewhat in a dorso-ventral direction, so that they can be better seen, but the projections are also much more prominent in this than in any other specimen in the collection. The actual structure is well shown in figure 3*b,* which is a detail enlarged from a specimen of which the projections cannot be seen in the complete figure.

The constancy in the number of secundibrachs in this form at three is interesting. In 23 specimens, of which 154 secondary arm-branches are exposed, only 12 vary from the regular number—most of these being in one specimen which has seven out of eight visible branches with 4 IIBr; in 19 out of the 23 specimens there is no variation.

Roemer (Bronn's Lethaea Geognostica, vol. 1, p. 236) took this species for the type of *Cyathocrinus,* which it is not any more than it is of *Taxocrinus.* Schlotheim referred it to *Encrinites,* and Pacht to *Dimerocrinites* associating it with his *Dimerocrinites oligoptilus* (now the type of *Dactylocrinus*). D'Orbigny referred it to Hall's *Cupulocrinus,* now known to be a transition form between the Flexibilia and the Inadunata. But Phillips recognized its true affinities, and it has been treated by him and those following him who understood his genus *Taxocrinus* as the best known representative of that genus, until I separated it in 1902 on account of the radianal. The structure of the anal side had never been understood until then, while the relation between the anal and interbrachial plates and the perisome is now for the first time described.

*Temnocrinus tuberculatus* is one of the best known crinoids of the fossil beds at Dudley, England; it has always been much sought for by collectors, and specimens of it are found in the leading paleontological museums of the world. In addition to Miller, it has been figured by Schlotheim, Goldfuss, Murchison, Quenstedt, Pictet and Baily.

*Types.* The original of Miller's figure 1 was formerly in the Ashmolean Museum at Oxford, but like many other of Miller's types is now mislaid or lost. The original of my figure 15 is in the British Museum, and the other specimens figured are in my collection.

*Horizon and locality.* Silurian, Wenlock Group; Dudley, England.

## **MERISTOCRINUS** Springer

*Plate XVII, figs. 1-9*

*Meristocrinus* Springer, Jour. Geology, XIV, 1906, pp. 515, 519.—Bather, Ann. and Mag. Nat. Hist., (8)XII, 1913, p. 389.—Zittel-Eastman, Textbook Paleontology, 1913, p. 204.
*Cyathocrinus*, Angelin (in part), Icon. Crin. Sueciae, 1878, p. 23 (not Miller).
*Gnorimocrinus* Wachsmuth and Springer (in part), Revision Palaeocrinoidea, pt. 1, 1849, p. 50.

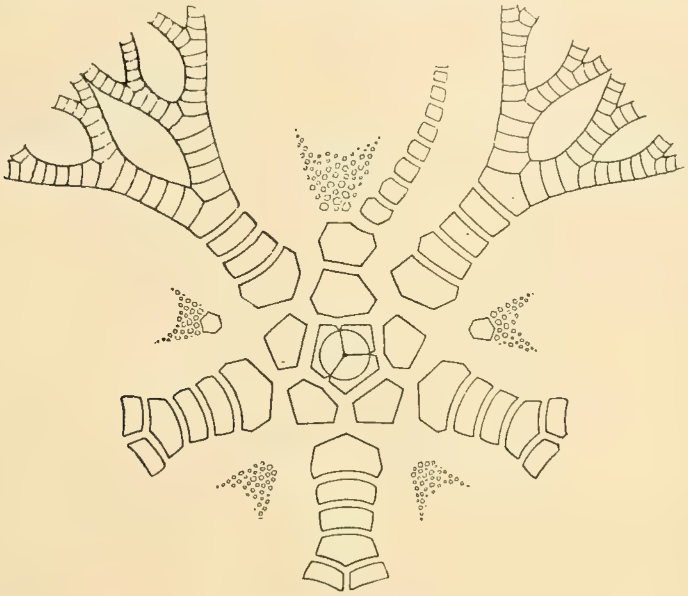

FIG. 23. *Meristocrinus*

Sagenocrinidae with rays above radials separated by perisome with or without a few solid plates in lower part. Crown elongate, expanding above radials. Infrabasals recumbent, taking small part in the formation of the calyx wall. Radianal usually in form of an infer-radial under right posterior ray. Anal *x* followed by others in series tending to form a tube. Interbrachials few and small (or wanting) in lower part of areas, followed by perisome. Primibrachs three. Arms dichotomous, divergent. Column large, expanding toward calyx.

*Genotype. Cyathocrinus interbrachiatus* Angelin.

*Distribution.* Silurian; Gotland and England.

This genus is the least satisfactory of those proposed by me in 1906, and the species now grouped under it are a sort of hodge-podge of forms for which no better place is found. We are embarrassed by abnormal or imperfect specimens in most of the species, and it is by no means certain that they all belong together. The genus was proposed mainly to receive some Silurian forms with a radianal and three primibrachs. Species so constructed might perhaps, in conformity with what has been found advisable in some other cases, be treated as variants of genera with a radianal and only two primibrachs, and would then fall under either *Temnocrinus, Protaxocrinus* or *Gnorimocrinus*. But the species here grouped do not exactly agree with any of those genera in other details, so I have concluded to let the genus stand for what it is worth. The species designated by me as the type of *Meristocrinus* was the form originally described as *Cyathocrinus interbrachiatus* by Angelin. When Wachsmuth and Springer proposed the genus *Gnorimocrinus* to receive the Swedish *Taxocrini* two species were thus brought together with the same name, so they renamed this one *G. loveni.* With its removal to another genus in which there is no such clash of names Angelin's priority must be recognized and the original name restored; therefore the type of *Meristocrinus* is *M. interbrachiatus,* instead of *M. loveni* as formerly stated by me.

Angelin's type specimen proves to be misshapen from injury and reparation during life (Pl. XVII, figs. 1*a-c*), but another one since found furnishes the characters upon which the genus is defined (figs. 2*a-d*). It will be seen from these figures that this genus is near the border line between Taxocrinidae and the other families in about the same way as *Synerocrinus.* The anal structure is that of a tube-like series; but because it does not originate on the posterior basal, from which it is separated by an anal plate suturally joined to the basal and adjacent brachials, the genus must be held to belong in the present family upon the principles already explained. The anal series is essentially similar to that of *Temnocrinus;* but the occurrence of so many different forms with an additional primibrach from several localities indicates that the modification is probably more than a mere sporadic or specific variation. In the typical form the genus may represent an intermediate step in the transition from *Temnocrinus* to the Carboniferous *Forbesiocrinus.*

The five species include forms from Gotland and England. They are a heterogeneous lot and do not lend themselves to systematic analysis.

### **Meristocrinus interbrachiatus** (Angelin)

*Plate XVII, figs. 1-3*

*Cyathocrinus interbrachiatus* Angelin, Icon. Crin. Suec., 1878, pl. 23, figs. 2, 2*a;* pl. 29, fig. 78.
*Gnorimocrinus loveni,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 50.
*Meristocrinus loveni,* Springer, Jour. Geology, XIV, 1906, p. 515.

Type of the genus.

A rather large species. Crown elongate, height to width at $IIBr_4$, 1 to 1. Spread of calyx from base to IAx, 1 to 3. Rays deeply rounded, interbrachial areas depressed. Base broad, tapering gradually to the expanded column. Sutures straight. Surface smooth. Maximum crown, 35 mm. high by 22 wide; base, 7 mm.

IBB appearing as low pentagons above the column. BB large, but smaller than RR. RA smaller than R. Anal *x* large, followed by a vertical series not over half its width, adjoining right posterior ray and bordered by perisome at the left. iBr one or two small plates followed by perisome which extends to the second and third axil. RR the largest plates in the calyx. IBr 3, decidedly shorter than RR but nearly as wide. IIBr 4 to 6, with two or more bifurcations above. Column large, composed next to calyx of very thin ossicles, and slightly narrowing downward.

The description is made chiefly from figures 2*a-c* of Plate XVII, but with corroboration from the other specimens. The type is abnormal, and singularly enough another specimen of this rare species characteristic in other respects is also abnormal in the anal side (Pl. XVII, fig. 3*b*).

*Types.* Riks Museum, Stockholm.

*Horizon and locality.* Silurian, Wenlock Group; Faro (horizon *d*) and Wisby (horizon *f*), Gotland, Sweden.

### **Meristocrinus orbignyi** (M'Coy)

*Plate XVII, fig. 7*

*Taxocrinus Orbignii* M'Coy, Ann. and Mag. Nat. Hist. (2), VI, 1850, p. 289; (in Sedgwick & M'Coy) British Palaeozoic Fossils, 1854, p. 53, pl. 1D, fig. 1.—Phillips Murchison, Siluria (3d Ed.), 1859, pp. xx, 246, 536.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 49.
*Meristocrinus orbignii,* Springer, Jour. Geology, XIV, 1906, pp. 492, 519.

The species is not well enough known for detailed description, but in connection with the next following species it shows the existence of a form of this generic type in the British rocks at two distinct horizons and localities. The only available specimen is the type which is a natural mould of the anterior side only, from which I have obtained a wax impression but not in time for figuring in this work. I reproduce M'Coy's figure which is much restored, but shows the essential characters as they appear in the original, viz., three primibrachs, five secundibrachs, and a large stem with remarkably uniform columnals, not enlarging at the calyx; it differs in the latter respect from the other species in which the stem is known.

*Type.* In the Sedgwick Museum at Cambridge, England.

*Horizon and locality.* Silurian, Upper Ludlow formation; High Thorns, Underbarrow, Kendal, County Westmoreland, England.

### **Meristocrinus minor** n. sp.

*Plate XVII, figs. 8, 9*

A small species. Crown elongate, total height to width at IAx, 2.5 to 1; spread of calyx from base about 1 to 2; average specimen, 10 mm. high by 4 mm. wide; base, 2 mm.

IBB low, like a short columnal. BB small. RR twice as large as BB, or as the succeeding IBr. IBr 3. IIBr 5. Anal and iBr areas distinct, the latter apparently without solid plates and filled with perisome. Column large, with conical expansion proximally, in which the columnals are very thin, becoming thicker and uniform below.

I have proposed this species upon the evidence of three specimens which show great uniformity in size and other ascertainable characters. The posterior side is visible only in one (Pl. XVII, fig. 9), and there the anal plates are indistinct, being pushed inward; apparently the first anal plate is firmly wedged in between the large radials, and is followed by a vertical series leaning toward the right posterior ray. The latter ray plainly shows the five plates in succession, viz., RA+R+3 IBr. The two specimens were obtained by me at Dudley in 1887, and referred to *M. orbignyi.* The subsequent discovery of a third specimen from the same horizon and locality, identical with them in size and stem characters, indicated a persistence of type which cannot well be ignored. They occur in the shales at the base of the Wenlock beds, a horizon considerably lower than that of *M. orbignyi,* which also comes from a different and somewhat distant locality. The expanding stem of the present species is sufficient to distinguish it from the last, and the very small infrabasals from the Swedish species.

*Types.* That of figure 9 is in the author's collection; of figure 8 in the British Museum.

*Horizon and locality.* Silurian, Wenlock shales; Dudley, England.

### (?) **Meristocrinus tuberosus** n. sp.

*Plate XVII, fig. 6*

I have designated under this name a crushed specimen with 3 IBr and a strongly differentiated tube, which seems to be separated from the basal by another plate; yet the structure is not certain, and the species may not belong here. The radianal is different from that of the generic type, being obliquely to the left of the posterior radial. If the base of the anal series were entirely free on one side this form would be a *Gnorimocrinus* with 3 IBr, and might be placed under that genus as a variant.

*Type.* Riks Museum, Stockholm.

*Horizon and locality.* Silurian, Wenlock Group, horizon *c;* Wisby, Island of Gotland.

### (?) **Meristocrinus anceps** n. sp.

*Plate XVII, figs. 4, 5*

The two fragmentary specimens in the Riks Museum to which I have given this name have a different anal structure from any of the foregoing. They are of the type having three primibrachs with widely diverging arms, like the last; the radials are much larger and more elongate than in any other species, and the facet does not occupy the entire distal face. The posterior ray is not preserved in either to the first bifurcation, but what I suppose to be the radianal is situated in the oblique position, and it is pentagonal instead of rhombic. It is followed by two good-sized plates meeting the distal faces, and these quickly pass into perisome without any vertical series or transverse line of separation, but with a rather distinctly rounded median prominence. So far as can be seen the two specimens are alike in this respect, and there appears to be a definite anal structure conformable to that of this family. They may not belong to this genus, but there is in them a curious suggestion of structure analogous to what is seen in the two abnormal specimens of *M. interbrachiatus* (Pl. XVII, figs. 1*c* and 3*b*), where the anal plates tend to pass into coarsely plated perisome without any tube intervening.

*Types.* Riks Museum, Stockholm, Sweden.

*Horizon and locality.* Silurian, Wenlock Group, horizon *d;* Wisby, Island of Gotland.

## **SAGENOCRINUS** Austin

*Plates XVIII, XIX*

*Sagenocrinites* Austin and Austin, Ann. and Mag. Nat. Hist., X, 1842, p. 110. Ann. and Mag. Nat. Hist., XI, 1843, p. 205.

*Sagenocrinus,* Bronn, Lethaea Geognostica, I, 1856, p. 22; Klassen u. Ord. Thier-Reiches, II, 1860, p. 231.—Roemer in Bronn, Lethaea Geognostica, II, 1852-54, p. 228.—Pictet, Traité Paleontologie, IV, 1857, p. 323.—Angelin, Icon. Crin. Sueciae, 1878, p. 8.—Von Zittel, Handbuch Palaeontologie, I, 1879, p. 375; Grundzüge Palaeontologie, 1895, p. 130 (*Sageniocrinus*).—Oehlert, Bull. Soc. Geol. France (3) VII, 1879, p. 7, Sep. (1878), p. 2.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 2, 1881, p. 201; *ibid.,* pt. 3, 1885, p. 99; Proc. Acad. Nat. Sci. Philadelphia, 1888, p. 357; *ibid.,* 1890, p. 388.—Jaekel, Zeitschr. deutsch. geol. Gesell., XLIX, 1897, p. 46.—Bather, Geol. Mag. (Dec. IV) V, 1898-99, p. 428; Treatise on Zoology (Lankester), pt. 3, 1900, p. 190.—Springer, Mem. Mus. Comp. Zool. Harvard, XXV, 1901, p. 71; Amer. Geologist, XXX, 1902, p. 89; Jour. Geology, XIV, 1906, p. 518.—Zittel-Eastman, Textbook Paleontology, 1913, p. 204.

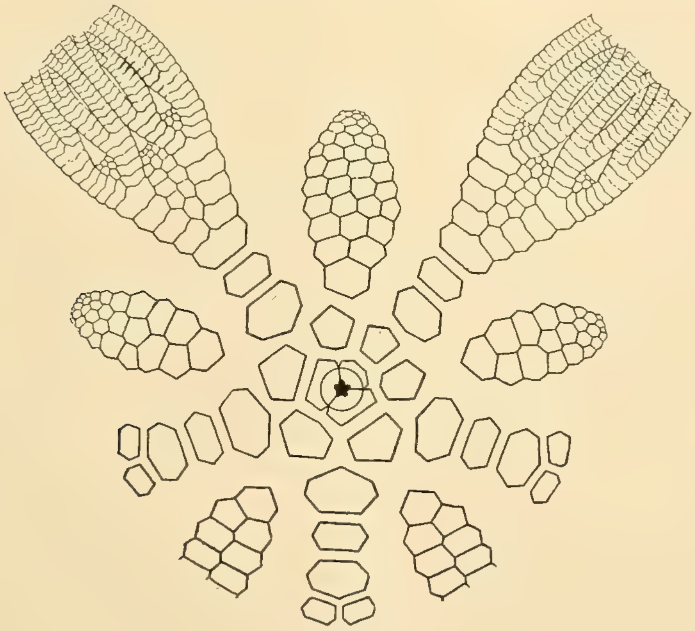

FIG. 24. *Sagenocrinus*

Sagenocrinidae with rays separated by interbrachial plates in wide areas. Crown elongate, ovoid to biturbinate. Infrabasals usually recumbent, taking small part in the formation of the calyx wall. Radianal obliquely under right posterior ray, more or less between basals, usually touching infrabasals. Posterior basal not materially larger than the others. Anal and interbrachial areas completely filled by numerous solid plates in more than one series. Primibrachs two. Arms dichotomous, not abutting. Column large, not expanding at the calyx.

*Genotype. Actinocrinites ? expansus* Phillips.

*Distribution.* Silurian; England, Gotland, and the United States.

The most striking morphological feature of *Sagenocrinus* is one the taxonomic value of which was overlooked until pointed out by me in 1902, and that is the presence of a radianal interposed within the ring of basals, and usually touching the infrabasals. It thus occupies the same position among the Flexibilia that *Thenarocrinus* does among the Inadunata. The plate is not so primitive as the radianal of *Homalocrinus,* which is directly under the right posterior radial; whereas here it is angular above, lying obliquely below the right posterior radial, and abutting also upon the anal plate. Except in one species, the radianal is interposed to a variable extent between the two basals, resting upon the infrabasal circlet. This fact was observed by Angelin without comprehension of its significance; he described the genus as having "parabasalia sex," but his observation did not attract attention. The position of this plate would seem on first thought to be the most primitive of all, but it is really not so; for the radianal has moved out of its original position as an infer-radial, and is no longer in contact with the right anterior radial, but has become an element in the posterior interradius. Whether it remains entirely between the two basals or not is purely a matter of degree in its development; its lower face varies in width of truncation, and if this narrows to a point the radianal becomes rhombic instead of pentagonal, and no longer connects with the infrabasals (Pl. XIX, fig. 5), but its essential position relative to other structures remains substantially the same. It is only a short step from this to an anal structure like that of *Forbesiocrinus agassizi,* where the anal plate on the longer right shoulder of the posterior basal is clearly equivalent to the radianal pushed upward with the enlargement of the posterior basal. Owing to the small size of this basal in *Sagenocrinus* the radianal, even when lifted up from between the basals as in the case above mentioned, is still below the level of the radial, touching its lower shoulder; whereas in *Forbesiocrinus,* by reason of the pronounced elongation of the basal this plate lies above the level of the radial, resting upon its left shoulder. This marked contrast in the proportions of the posterior basal in the two genera is a very important point in their separation.

*Sagenocrinus* differs from the antecedent genera of the family in having the interbrachial areas completely filled by numerous massive plates, joined to each other and to the brachials of adjacent rays by suture; these rise to the height of the upper secundibrachs, thence passing in between the arm bases, and gradually into the plated integument of the tegmen. They form with the brachials an apparently solid calyx wall resembling that of the Camerata, and in this respect the type is the same as that of *Forbesiocrinus.* The arms in this genus are relatively long and slender, and appear as if given off from the upper edge of the massive calyx much like those of some Camerata. The stem differs from the prevalent type in this group in having no enlargement or series of very thin columnals at the proximal end· it commences at the calyx with alternating ossicles of nearly equal diameter, and continues cylindrical so far as known.

The Austins in proposing the genus treated it as belonging to their family Periechocrinoidea.[1] Their generic description [2] was not very lucid, the dorsal side of the calyx being unknown; they relied chiefly upon the presence of a "plated integument, which extends between their lower divisions (of the rays) in the same manner as the membranous web is stretched between the toes of many aquatic birds,"—a construction which they declare "clearly proves them to belong to an undefined genus." This "plated integument" is only the extension of the interbrachial plates in decreasing size between the rays and their divisions, and probably does not refer to any tegminal structure observed by them. In addition to Phillips's *S. expansus* (which he had placed provisionally with the *Actinocrinites*) they describe a new species, *S. giganteus,* of which the "body-plates (were) unknown," but in which "a plated integument connects the lower portions of the rays." No further light was thrown upon the essential characters of the genus until Angelin's time, although the type species is one of the most striking fossils of the famous locality at Dudley, England, where it was not uncommon; and good representatives of it were to be found in most of the prominent collections in England.

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[1] Ann. and Mag. Nat. Hist., Ser. I, vol. 10, 1842, p. 110.

[2] *Ibid.,* vol. 11, 1843, p. 205.

D'Orbigny in his Prodrome Paleontologie, vol. 1, 1849, p. 46, ignored Austin's genus altogether, and referred Phillips's species to *Glyptocrinus*, in which he was followed by Murchison in 1859 in Siluria, p. 247. Bronn in the Lethaea Geognostica, 1851-6, vol. 1, p. 22, referred the genus to the Periechocrinidae of Austin; while Roemer in the same volume, p. 228, placed it under a family of its own, as did Angelin in 1878. Pictet (Traité Pal., vol. 4, 1857, p. 323) placed it under his second tribu, Actinocriniens. Von Zittel in 1879 (Handb. d. Pal., vol. 1, p. 375, and Grundzüge Pal., 1895, p. 130) referred it to the Glyptocrinidae. Angelin (Icon. Crin. Suec., 1878, p. 8) for the first time gave a description and figures showing the construction of the calyx, on the strength of which Wachsmuth and Springer (Rev. Pal., pt. 2, 1881, p. 201), though noting a resemblance to *Taxocrinus*, ranged the genus under the Rhodocrinidae. They considered Angelin's statement of " sex parabasalia " to be a mistake; but they could not believe the sixth plate to represent an anal, " as no plate of that kind has ever been observed below the line of radials."

When in England in 1887-88 I had for the first time an opportunity to see and obtain good specimens of Phillips's species, and was immediately convinced that their relationship was with the Flexible crinoids; in a note to our paper on the ventral structure of *Taxocrinus* (Proc. Acad. Nat. Sci. Phila., 1888, p. 357) Wachsmuth and I referred the genus to the Ichthyocrinidae, in which family the whole group was then included.

After all the shifting of opinion as to the systematic position of this genus, and its final settlement in a firm place among the Flexibilia, it is interesting to note that this relationship was perceived as early as 1841 by that sagacious observer, John Phillips, who when proposing for certain species his Taxocrinoid genus under the preoccupied name *Isocrinus* (Pal. Foss. Cornwall, p. 29) said: " Perhaps *Actinocr.* (?) *expansus*, of Sil. Researches, may be allied to them." To a similar effect was the suggestion of De Koninck and Le Hon in proposing their genus *Forbesiocrinus* (Crin. Carb. Belgique, 1854, p. 121, note), that " it is not impossible that *Actinocrinus* ? *expansus*, Phill., belongs to this genus."

So much was I impressed with the resemblance of the Dudley specimens to the American *Forbesiocrinus agassizi* that I was disposed, in view of the doubts as to the validity of the name *" Forbesiocrinus,"* to think that all the American species described under it might be referred to *Sagenocrinus;* a view which was substantially taken by Bather (1900, Lankester's Zoology, pt. 3, p. 190), and which I afterward expressed in 1901 (Mem. Mus. Comp. Zool., vol. 25, no. 1, p. 71). In these views both of us, as well as all previous writers, overlooked the significance of the " sixth parabasal " of Angelin, which instead of being a mistaken character, as too hastily supposed by Wachsmuth and Springer, is a constant element in all the specimens as the radianal within the ring of basals—one of the most remarkable and distinctive characters to be found in this entire group. This was pointed out by me in 1902 (Amer. Geologist, vol. 30, pp. 89, 94), and the distinction between the two genera clearly shown, in connection with the description of an American species from the Niagaran of Waldron, Indiana. This species, as there stated, is not fully characteristic in the position of the radianal, which does not touch the infrabasals although occupying substantially the same relative position. Since that time, however, a species having all the characters of the English and Swedish specimens has been found in the American Silurian, so that the geographical range of the genus is confirmed by an unquestionable species.

In default of any constant diagnostic characters for separating them the English and Swedish forms must remain together under the type species as Angelin placed them, while those from America may be distinguished as indicated in the following analysis:

### The Species of Sagenocrinus

I. Sutures between brachials usually straight.
    RA completely between BB, touching IBB.
        Arms strong; RR largest plates in calyx.
            Plates without ridges .......................................... *S. expansus.*
            Median ridge upon RR and Br plates .................................. *S. clarki.*
II. Sutures between Br distinctly sinuous.
    RA only partly between BB, not touching BB.
        Arms delicate; BB largest plates in calyx.
            Plates without ridges ........................................ *S. americanus.*

*Sagenocrinites giganteus* Austin is not distinguishable from *S. expansus.*

## **Sagenocrinus expansus** (Phillips)

*Plates XVIII, figs. 1-9; XIX, figs. 1-3*

*Actinocrinites* (?) *expansus* Phillips in Murchison, Silurian System, 1839, p. 674, pl. 17, fig. 9; Palaeozoic Fossils Cornwall, 1841, p. 29.—Quenstedt, Petref. Deutschlands, IV, 1876, p. 594.

*Sagenocrinites expansus,* Austin and Austin, Ann. and Mag. Nat. Hist., X, 1842, p. 110; *ibid.,* XI, 1843, p. 205.

*Sagenocrinus expansus,* Morris, Catalogue British Fossils, 1st Ed. 1843, p. 58 (2d Ed., 1854, p. 89).—Pictet Traité Paleontologie, IV, 1857, p. 323.—Angelin, Icon. Crin. Sueciae, 1878, p. 8, pl. 15, figs. 6, 8, and ?Pl. 27, figs. 8*a*, *b*, ?Pl. 28, fig. 8.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 2, 1881, p. 203; N. A. Crinoidea Camerata, 1897, p. 219.—Springer, Jour. Geology, XIV, 1906, pl. 7, figs. 18, 19.

*Carpocrinus expansus,* Muller, Phys. Abhandl. K. Akad. Wiss. Berlin, 1843, p. 209.

*Glyptocrinus expansus,* D'Orbigny, Prodrome Pal. Stratigraphique, I, 1849, p. 46.—Murchison, Siluria, 1859, p. 247; also Salter in appendix to same, p. 535.

*Glyptocrinus* ? (*Actinocrinites* ?) *expansus,* Murchison, Siluria, 1859, pl. 15, figs. 1, 2.

*Rhodocrinites verus* Miller (in part), Nat. Hist. Crinoidea, 1821, p. 107, pl. 1, fig. $\frac{1}{A}$.

*Rhodocrinus verus,* Roemer in Bronn, Lethaea Geognostica, 1852-1854, p. 241, pl. 4, figs. 2*a-e*.

*Sagenocrinites giganteus* Austin and Austin, Ann. and Mag. Nat. Hist., X, 1842, p. 110; *ibid.,* XI, 1843, p. 205.

Type of the genus.

Specimens attaining a large size. Crown oblong, with arms infolding. Calyx turbinate to hemispheric, with side outline more or less curved; widest at $IIBr_3$, where cross-section is circular, or slightly decagonal from the depression of iBr and iIIBr spaces; height to width, about 1 to 1.2. Plates evenly curved, without radial ridges; smooth, or marked with crescentic wrinkles parallel with margin of plates; sutures straight and slightly beveled. Spread of calyx from base to $IIBr_3$, 1 to 5. Crown of large specimen, 85 mm. high by 53 mm. wide; base, 10 mm.; small specimen, 15 mm. by 12 mm., base, 3 mm.

IBB visible as low pentagons in side view. BB smaller than RR; post. B but little different in shape from others. RA a pentagonal plate, truncate below and of variable width where touching IBB, and angular above where it meets the anal plate and r. post. R. iBr in 6 to 9 ranges before passing into the tegmen; the first plate angular above, supporting two vertical series of gradually diminishing plates which extend between and beyond the arm bases, and curve inward upon the tegmen without visible interruption; a third series is often interposed between the two half-way up; similar series of plates of correspondingly smaller size and number fill the iIIBr and iIIIBr areas, likewise passing into the tegmen. Anal area similar to the others, usually with an additional vertical series in the middle, at least part way. Anal *x* not materially different from $iBr_1$, and not larger than succeeding anal plates. RR the largest plates in the calyx; brachials regularly diminishing upward to the arms, which become free in young specimens about the upper IIBr, in older ones not until the next bifurcation. IBr 2; IIBr usually 3, exceptionally 2 or 4. Arms long, usually infolding over the tegmen; rounded or somewhat angular on the back, deep, bifurcating in mature specimens four or five times or more after becoming free, and extending to very long, slender, closely coiled finials. Column large, without proximal enlargement, composed from the calyx down of short projecting columnals alternating with shorter and narrower ones; 6 pairs in upper part make a length about equal to the diameter; composition of distal end unknown.

Notwithstanding this is one of the best known fossils of the famous locality at Dudley, there is no satisfactory type figure for the species. Miller's is a composite formed from the arms of a Dudley specimen and the calyx of a Carboniferous *Rhodocrinus;* this was afterwards elaborated in Bronn's Lethaea Geognostica, table 4, figure 2. Phillips's specimen was imperfect, being a crown minus the calyx below the upper secundibrachs; but his figures are sufficient, when taken in connection with the numerous good specimens now available for study, to determine the form beyond any doubt. I have copied his principal figure, reduced to the probable size of the specimen (Pl. XVIII, fig. 1). The series of specimens from my own collection which I have figured shows the species in almost every variation of age, size, contour and surface preservation. The peculiar marking of the plates by concentric bands shown in figure 9 is seen more or less distinctly in some other large specimens, and it may have been a condition of mature growth; the original of figure 3 has obscure traces of a radiating marking on the plates, that of figure 4 a faint tubercular ornamentation. Not enough constancy can be found in these appearances to warrant specific distinctions.

Some variation in the position of the radianal may be observed in the specimens; while it is always in contact with the infrabasals, the relative breadth of its lower face varies, and in figure 5 the radianal extends higher than usual between the radial and anal *x*, almost far enough to separate them. There is also in some specimens a tendency of the first interbrachial in the regular areas to pass down to a connection with the basals. None of the specimens show any indication of the so-called " patelloid " processes, nor sinuous sutures, except slight traces in the arms.

Angelin recognized the species among the crinoids from the Wenlock beds of Gotland, and figured three specimens, of all of which I have given new figures. It might be said that the arms seem a little heavier in the Swedish specimens than in the English, and in some the calyx relatively higher; but the differences can hardly be defined specifically.

*Types.* The original of Phillips's figures in the Silurian System is said by Murchison to have been in the collection of Mr. Benjamin H. Bright, near Dudley, England, but I have been unable to trace its present whereabouts. The other English specimens figured herein are in my collection, and those from Gotland in the Riks Museum.

*Horizon and locality.* Silurian, Wenlock Group; Dudley, England, and Follingbo (horizon *f*), Gotland, Sweden.

### **Sagenocrinus clarki** n. sp.

*Plate XIX, figs. 4a-d*

A large species. In general form similar to *S. expansus,* but differing decisively from it by having a sharp abrupt median ridge following the brachial series from near the radials to the arm bases. Calyx plates seem thinner, arms relatively shorter, and base narrower. Sutures straight in the calyx, not beveled; slightly sinuous in the arms.

The unique type specimen was found near the close of the collecting in the Niagaran beds near Decaturville, Tennessee; it is badly crushed, but by patient cleaning I have been able to expose both sides so that all the essential characters may be observed. The best preserved side is so much distorted that a direct figure of it would give little information, but the form and proportions of the plates can be accurately determined by measurement and by observation from different angles not possible to show in a figure. From these sources a careful restoration has been made from the anal side, which gives the normal contour and proportions of the crown. The radianal is much narrower than the adjoining basals, especially at the lower margin, as may be seen from the restoration and diagram on Plate XIX, figures 4*b, d;* and it is relatively narrower than I have observed in any specimen of *S. expansus.* Without changing the relative positions of plates, a little further lateral crowding of the basals would detach this plate from the infrabasals and put it in substantially the same position as that of *S. americanus.*

The general outline of the calyx is more rotund than in most English and Swedish specimens, although when compared with a perfectly preserved and undistorted calyx of *S. expansus,* such as Plate XVIII, figure 3, the difference in this respect is not striking. The narrow, abruptly raised median ridge along the brachials is a decisive character, of which no trace has been seen in the other species. There is probably also a difference in the less uniformity of the columnals in this species; parts of the column in several specimens of *S. expansus* other than those figured show it to be very regular in the alternation of narrow and wider ossicles of very uniform length. In the figure of this specimen may be seen a large number of very small plates scattered promiscuously over the calyx; it is not certain that they belong to it, but as there was no other crinoid in immediate contact it is probable they do, and if so can only be remnants of the tegmen pushed through between the arm bases by pressure during deposition at the sea bottom.

The great similarity of many other crinoidal forms of this locality with those of Dudley and of Gotland would lead us to expect a greater resemblance of this species to the European type than to the other American species.

The specific name is proposed in honor of Mr. Austin Hobart Clark as a slight evidence of my appreciation of his great work on the Recent crinoids.

*Type.* Author's collection.

*Horizon and locality.* Silurian, Niagaran Group, Brownsport limestone, Beech River formation; Decaturville, Tennessee.

### Sagenocrinus americanus Springer

*Plate XIX, fig. 5*

*Sagenocrinus americanus* Springer, American Geologist, XXX, 1902, p. 88, text-fig.

A relatively small species. Crown elongate, with short arms. Calyx turbinate, side outline straight; height to width at IIBr$_3$, 1.2 to 1; spread of calyx, 1 to 3. Plates smooth, without ridges; radial and brachial series with decided sinuous sutures. Crown, 29 mm. high by 19 mm. wide; base, 6 mm.

IBB in erect pentagons relatively higher than in *S. expansus.* BB the largest plates in the calyx. RA obliquely below r. post. R, partly between BB, but not touching IBB. Anal *x* larger than iBr$_1$, or the succeeding plates in anal area. iBr in not over 5 ranges; iIIBr few. RR much smaller than BB. IBr 2; IIBr 3. Arms slender and apparently short. Column large, tapering but slightly from the calyx, with slight alternation of thin and thicker columnals.

As but one specimen of the species is known, it has been thought possible that some of the characters above given may be individual, especially the position of the radianal, which departs from the typical form of the genus in not being within the basal ring and therefore not passing down to the infrabasals. It is more probably, however, a specific character correlating with the greatly increased size of the basals, which tended to crowd it upward to make room for themselves. The difference in relative size of the calyx plates between this and the other species is very marked, the radials being the largest plates in *S. expansus,* while here the basals are much the largest; this produces a higher and much less expanding calyx, as a comparison of the measured proportions will show. The arms are of extreme delicacy for this genus, and must have been short, as they infold and disappear from view between the first and second bifurcations after becoming free. These features, together with its well-marked sinuous sutures extending from radials into the arms, impart to this form a very different aspect from that of any specimen of the other species.

The position of the radianal inclined me at first to doubt if this species could be held within the genus; but further consideration showed that the difference is rather one of degree than of kind, and relates to a character which is somewhat variable in the typical species. The radianal of typical *Sagenocrinus* is not in the position of an infer-radial directly at the base of the ray and connecting with the radial of the adjacent ray, as is the case with all forms having the radianal in the primitive position; it has shifted from that position, and although resting very low down, within the ring of basals, it lies nevertheless obliquely outside of the ray, and belongs to the anal, or interradial, rather than to the radial structures. Variability in the extent to which it has grown either upward or downward may therefore well exist within the same genus.

The type specimen is from the Waldron beds of the Niagaran at the noted fossil locality at Conn's Creek, near Waldron, Indiana, and was obtained by the author many years ago from Dr. C C. Washburn, the veteran collector resident at the locality, whose extensive collection afterward passed to the University of Chicago. It is singular that among the many collections made in the same beds during more than 40 years no trace of another specimen was ever found. The horizon is considerably below that of *S. clarki,* and this may account for the great difference of this species from that, in all the characters wherein the latter resembles the European form.

*Type.* Author's collection.

*Horizon and locality.* As above stated.

## **LITHOCRINUS** Wachsmuth and Springer

*Plate XX, figs. 1-3*

*Lithocrinus* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 52; *ibid.*, pt. 3, 1886, p. 145.—Von Zittel, Grundzüge Pal., 1895, p. 138.—Zittel-Eastman, Textbook Palaeontology, 1896, p. 164 (2d Ed., 1913, p. 204).—Bather, Rep. British Assoc. for 1898 [1899], p. 923; Treatise on Zoology (Lankester), pt. 3, 1900, p. 189.—Springer, Amer. Geologist, XXX, 1902, p. 95; Jour. Geology, XIV, 1906, p. 515.

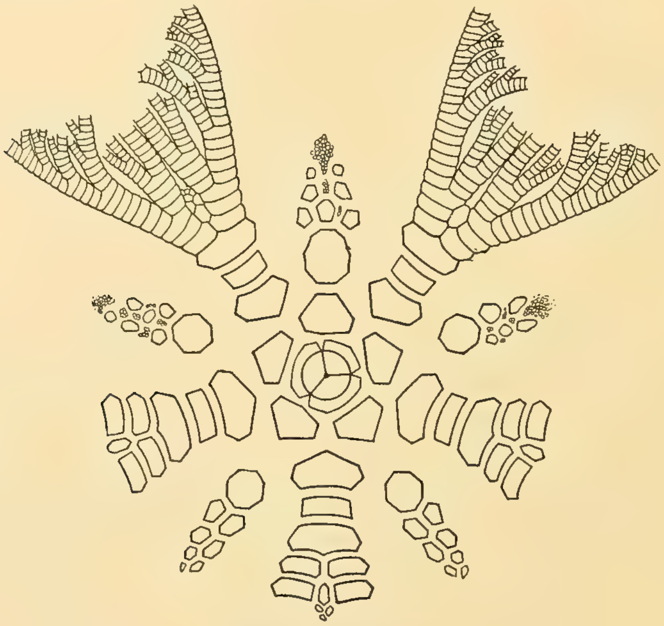

Fig. 25. *Lithocrinus*

Sagenocrinidae with rays above radials separated all around by interbrachial plates in lower part. Crown elongate. Infrabasals recumbent, taking small part in calyx wall. Radianal only in upper oblique position. Anal and interbrachial areas filled with solid plates in more than one series in lower part, followed by perisome passing into the tegmen. Primibrachs two. Arms heterotomous, divergent; rays in ten main divisions with branching ramules. Column large, cylindrical, not alternating at the calyx.

*Genotype. Forbesiocrinus divaricatus* Angelin.

*Distribution.* Silurian; Gotland, Sweden.

This genus, as now defined, contains the species remaining after the removal of *Lithocrinus obesus* under the name *Cholocrinus.* Proposed by Wachsmuth and Springer as a subgenus to include the Silurian species described by Angelin under *Forbesiocrinus,* its generic distinctness is well established and it may be better defined than we supposed at that time. We did not designate any type species, but this was supplied in 1899 by Bather, who proposed to restrict the genus to the type of *L. divaricatus.* The absence of a radianal and the presence of solid interbrachial plates in the lower part of the areas differentiates it sharply from *Cholocrinus,* to which it bears a superficial resemblance in the arm structures. The heterotomy has become better defined, the ramules being confined so far as known to the inside of the dichotom; they are still irregular in size, not diminishing gradually upward; the larger ones apparently occur about half way up, where they become almost as large as the main arm; the intervals vary from four to six or more brachials, and the ramules themselves bear secondary ramules, sometimes as many as four, also toward the inside of the dichotom. The primary ramules are large and long, not greatly different in appearance from the ten main ray divisions. A second subdivision of the ray, and the reduction of the ramules to a small size regularly diminishing upward and mostly unbranched, would produce the more regular and definite heterotomy of Devonian and Carboniferous genera such as *Dactylocrinus, Wachsmuthicrinus* and *Synerocrinus.*

The interbrachial structure is of considerable interest, as perhaps leading up to a puzzling condition found in the Carboniferous. It is solid in the lower part of the area, with a single large and well-defined plate; following this come a number of much smaller plates, the change in size being abrupt and not gradual, but at the same time not uniform. And here occurs a singular modification: the plates above the first interbrachial are not regular in size or shape, and from the first range they begin to be more or less isolated and surrounded by perisome; the area of solid plates diminishes until they are entirely replaced in the upper part by perisome which passes to the tegmen. This structure varies in the specimens, but is beautifully shown by figure 3*a* of Plate XX, drawn from a more mature specimen than the others; and it is to be compared with that of *Forbesiocrinus nobilis* as hereinafter described. The same structure is repeated in the second and higher axils. The anal area is not perfectly preserved in the upper part; it is very similar to the others, having one very large plate following the truncate basal, and the second range is differentiated merely by being a little wider and having a few more plates, as in *Sagenocrinus* and *Forbesiocrinus.* The stem is more like that of *Sagenocrinus* than *Cholocrinus.*

*Lithocrinus* is restricted to the Silurian, and has not been found outside of Gotland. The three species remaining in the original list after the removal of *L. obesus* have been further reduced by the suppression of *L. robustus* as a synonym; another, *L. mülleri,* must be ignored, as the type and only specimen cannot be found, and Angelin's figure is probably a reconstruction. This leaves *L. divaricatus* as the only species.

## **Lithocrinus divaricatus** (Angelin)

*Plate XX, figs. 1-3*

*Forbesiocrinus divaricatus* Angelin (in part), Icon. Crin. Sueciae, 1878, p. 9, pl. 21, fig. 21; pl. 28, fig. 3 (not pl. 26, figs. 6, 6*a* = Cholocrinus).

*Lithocrinus divaricatus,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 53.—Bather, Rep. British Assoc. for 1898 [1899], p. 923.—Springer, Jour. Geology, XIV, 1906, p. 515.

*Forbesiocrinus robustus* Angelin, Icon. Crin. Sueciae, 1878, p. 9, pl. 21, figs. 11, 12.

*Lithocrinus robustus,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 53.

Type of the genus.

Crown elongate, widest about level of first ramule, spread of calyx from base 1 to 3.3. Rays and their divisions deeply rounded, heavy, widely diverging, tapering slowly. Cross-section above IBr pentagonal. Surface marked with very fine granulose wrinkles. Crown of mature specimen, 52 mm. high by 20 mm. wide; base, 6 mm.

IBB forming a low cylinder above column. BB half as large as RR, sloping outward, post. B truncate. Anal *x* large, rising nearly to the height of the axillary IBr, followed by three plates abreast, and two or more ranges above. iBr one nearly as large as the anal, followed by others of irregular size, many of them isolated by surrounding perisome which becomes continuous above, passing into the tegmen; iIIBr areas similarly constructed, and perisomic plates also occupy the axils of lower ramules. RR the largest plates in the calyx, being both higher and wider than iBr. IBr 3, exceptionally two. Rays long, each ramus bearing five or more long ramules only from inside of dichotom; these are heavy, unequal, branching three or four times also from inside at intervals of 3 to 4 brachials, not diminishing regularly, but the first one smaller than the next. Column large, about flush with the infrabasal ring; composed from the calyx down of projecting columnals alternating with shorter and narrower ossicles, without any enlargement in upper part.

*Types.* All in the Riks Museum, Stockholm.

*Horizon and locality.* Silurian, Wenlock Group, horizon *f;* Wisby, Island of Gotland.

## **FORBESIOCRINUS** De Koninck and Le Hon

*Plates XX, figs. 4-8; XXI-XXXI; text-figs. 2a, b; 27; 29-31*

*Forbesiocrinus* De Koninck and Le Hon, Recherch. Crin. Carb. Belgique, 1854, p. 118.—Roemer in Bronn, Lethaea Geognostica, I, pt. 2, 1852-54, p. 235.—Pictet, Traité Paleontologie, 1857, p. 326.—Hall, Geol. Iowa, I, pt. 2, 1858, p. 628.—Bronn, Klassen u. Ord. Thier-Reichs, II, 1860, p. 231.—White, Boston Jour. Nat. Hist., VII, 1863, p. 497—footnote.—Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1865, p. 139; Geol. Surv. Illinois, II, 1866, p. 270.—Shumard, Trans. Acad. Sci. St. Louis, II, 1866, p. 371.—Beyrich, Monatsber. Akad. Wiss. Berlin, Feb., 1871, p. 43 (Transl. in Ann. and Mag. Nat. Hist. (4) VII, 404.—Quenstedt, Petref. Deutschlands, IV, 1876, p. 503; Handb. Petrefaktenkunde, 1885, p. 946.—Wachsmuth, Amer. Jour. Sci., XIV, 1877, p. 184.—Wachsmuth and Springer, Proc. Acad. Nat. Sci. Philadelphia, 1878, p. 252; *ibid.*, 1888, p. 353; 1890, p. 388; Revision Palaeocrinoidea, pt. 1, 1879, p. 51; *ibid.*, pt. 3, 1886, p. 145; N. A. Crinoidea Camerata, 1897, p. 77.—Von Zittel, Handbuch Palaeontologie, 1879, p. 353; Grundzüge Palaeontologie, 1895, p. 138.—Miller, N. A. Geology and Palaeontology, 1889, p. 246.—Jaekel, Zeitschr. deutsch. geol. Gesell, XLIII, 1891, p. 582.—Zittel-Eastman, Textbook Palaeontology, 1896, p. 164 (Ed. 2, 1913, p. 204).—Bather, Treatise on Zoology (Lankester), pt. 3, 1900, p. 190.—Springer, Mem. Mus. Comp. Zool. Harvard, XXV, No. 1, 1901, p. 71; Amer. Geologist, XXX, 1902, p. 89; Jour. Geology, XIV, 1906, p. 518.

*Proguettardicrinus* ? Steinmann, Geol. Grundlagen der Abstammungslehre, 1908, p. 153.

Not Angelin, Icon. Crin. Sueciae, 1878, p. 9 = *Lithocrinus;* nor Lyon and Casseday, Amer. Jour. Sci., XXVIII, 1859, p. 235 = *Onychocrinus;* nor Trautschold, Bull. Soc. Imp. Moscow, XL, 1867, p. 31 = *Synerocrinus.*

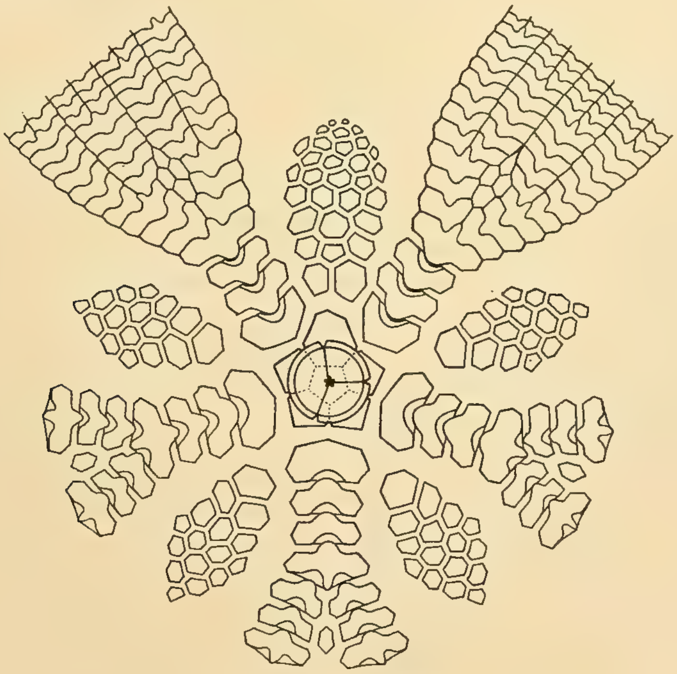

FIG. 26. *Forbesiocrinus*

Sagenocrinidae with rays above radials separated all around. Crown elongate ovoid. Infrabasals recumbent, taking small part in calyx wall. Posterior basal elongated. Radianal only in upper oblique position. Anal and interbrachial areas filled by solid plates in lower part, followed by perisome, or by solid plates extending to the tegmen; interbrachials in more than one series. Primibrachs three, exceptionally two. Arms dichotomous, usually divergent. Column large, enlarging proximally.

*Genotype.* *Forbesiocrinus nobilis* De Koninck and Le Hon.

*Distribution.* Lower Carboniferous, from base to Warsaw Group; Belgium and the United States.

No other genus of the Crinoidea Flexibilia has been involved in more confusion and misunderstanding than *Forbesiocrinus,* both on morphological and nomenclatorial grounds—so much in fact as to lead one eminent authority to suggest that the name be dropped altogether. This has resulted largely from a misconception of its relations with *Taxocrinus,* together with some uncertainty as to the exact limits of the genus as represented by the specimens of its type species. It therefore seems advisable to give a somewhat full discussion of the characters of the two genera, with the aid of information not possessed by previous authors; and it is hoped that some of the difficulties which have troubled paleontologists heretofore may be removed. In so doing I will take up the above mentioned causes of confusion in inverse order.

First, as to the definition and limits of the genus: It was founded by De Koninck and Le Hon upon two specimens from the Lower Carboniferous of Belgium in the lowest stage, the limestone of Tournai. These they erroneously identified with *Taxocrinus nobilis* of Phillips from the Mountain limestone of Yorkshire, England (Research. Crin. Carb. Belgique, 1854, p. 121, pl. 2, figs. *2a, b*). They figured both specimens under the name *Forbesiocrinus nobilis,* and gave a good generic diagram based upon them. They did not discover the existence of the infrabasals, but described the genus as being devoid of them, and upon that ground distinguished it and its ally, *Taxocrinus,* from *Cyathocrinus* and *Poteriocrinus* " with which they had often been confounded." This may be disregarded as an error due to deficient material, and to the unsuspected concealment of these plates under the column, which caused them to pass unobserved in genera belonging to this group by many of the earlier authors. Hall in 1858 (Geology of Iowa, vol. 1, pt. 2, p. 629), having several species to describe which he thought referable to De Koninck and Le Hon's genus, discovered in them three small plates below the so-called basals. He thereupon proposed a revision of the generic formula so as to include those plates, which he called " basals," and the five others above them " subradials," in the terminology of De Koninck and Le Hon.

The generic formula given by the authors (loc. cit., p. 118) among other things stated: " interradials 12 or 13; anals unknown." The latter clause is misleading; they only meant to say that the total number of anals was unknown, for in their generic diagram they figure five ranges of these plates; and in the diagnosis of generic characters, after stating that all four of the ranges of " pieces radiales " are joined to " pieces interradiales " to the number of 12 or 13 for each regular side, they add: " the number of *pieces anales* must be considerably more." And they proceed further: " That which distinguishes the anal side from the others is that the superior extremity of the corresponding basal piece is united to two small anal pieces, and that it has, in consequence, two articular facets more than the other four basal pieces." These statements are of the utmost importance in the discussion further on.

The two type specimens are both imperfect. That of figure *2a,* in the Muséum d'Histoire Naturelle, Paris, shows the general character of the rays and their divisions, and the tubercular surface ornamentation, but nothing whatever of the anal or interbrachial structures. The other specimen, figure *2b,* is in the Musée Royal d'Histoire Naturelle at Brussels. It is somewhat better preserved as to the parts wanting in the first, but it is in an unfavorable condition for observing all these structures with accuracy. It is very much flattened along the antero-posterior axis to a thickness of 15 mm., while the width is 75 mm. The authors figured it from the flattened anterior side where the ray is much injured; and no interbrachial plates are visible on either side of this ray, but at the left of the right anterior ray may be seen interbrachials to the height of at least four ranges. I have figured this interradial edge of the flattened specimen (Pl. XXII, fig. *1c*), and it shows the presence of some 8 or 10 plates in a more or less disturbed condition, pushed out of their natural order and sequence. The upper of these is no higher than the axillary primibrach, and although the two rays are preserved to considerably above the second bifurcation there is no sign of any interbrachials between them above the level mentioned. By reason of the flattening of the specimen by lateral pressure the interbrachials which are shown would be forced up higher than their natural position, and the lines and angles of their sutures would be much altered.

At the opposite side, where the interbrachials are similarly squeezed out of their normal position, only four or five are visible pushed into a vertical row to the same height as the others, with no indication of any plates between the rays above the level of the last primibrach (Pl. XXII, fig. 1*d*). Therefore at the most this specimen shows the presence of from 4 to 8 or 10 interbrachials occupying the lower part of the area only. I have given a figure of the posterior side, which was not done by the authors (Pl. XXII, fig. 1*b*). The posterior basal is perfectly plain, angular above, followed by two plates suturally united to it, with others succeeding them; at the right two or three more are indistinctly shown, tending to form a series bordering the right posterior ray. At one place a single intersecundibrach is seen.

No other specimens were known to De Koninck and Le Hon; and upon the data furnished by the one at Brussels they constructed their generic diagram (Pl. XXII, fig. 2). This was substantially correct as to the form of the posterior basal and one or two ranges of anal plates succeeding it. It shows interbrachials in one area to the number of 10, with 3 more indicated by dotted lines to fill out the arrangement as it was supposed to be. This, of course, was taken wholly from the right posterior interradius now shown by my figure 1*c;* and while it is possible to deduce such a number and arrangement from what appears there, I should consider this somewhat doubtful when taken in connection with the much smaller number just as plainly shown at the left posterior interradius.

Since De Koninck's time three more important specimens of this species have been found in the same lower limestone beds at Tournai, all of which came into my possession, and are figured upon Plate XXIII. Two of them are of the same large size as the types, have the same surface ornament and the same deeply rounded rays and ray divisions, with wide interbrachial spaces between them. Each of these has the same angular posterior basal with two good sized anal plates suturally united to it, and two or three much smaller ones in a second range; and in both one or more interbrachial areas are preserved with all the plates in their natural position. These specimens are in good condition, having come out of a soft matrix readily removed by cleaning, and while somewhat broken in collecting they were easily put together, so that I do not think any important solid structure is missing except possibly a few small plates at the right side of the anal interradius. A third specimen, consisting only of the stem, infrabasals, and two basal plates, has the posterior basal with the same angular sutural margin (fig. 3). All three have the infrabasals distinctly visible.

It will be observed that the primary interbrachial structures are the same in the two complete crowns, consisting of one quite large plate followed by three smaller ones abreast, with a crescentic distal margin following the curvature of the margin of the brachials with which they connect, and rising to about the middle of the second primibrach. Upon comparing the figures of these specimens with those of the type as interpreted by De Koninck and Le Hon, it will be seen that the only difference between them lies in the possibly greater number of anal plates in the latter, and of interbrachials in one area; the other area preserved would have about the same number as in my specimens. There can therefore be no reasonable doubt that these later acquired specimens, from the same horizon and locality, represent the same form as De Koninck and Le Hon's types; and we are accordingly warranted in looking to them for the generic and morphological characters which they exhibit so much more clearly.

I have given the foregoing recital of facts with what may seem a wearisome prolixity of detail, but I have a definite reason for it. Beginning with Hall in 1858, a large number of species from the American Lower Carboniferous have been described by several of our best paleontologists, including Lyon, and Meek and Worthen, under the name *Forbesiocrinus.* The type to which these species belong has always attracted the attention of collectors and authors on account of its striking appearance and well marked characters, and specimens of some of the species have been considered the greatest prizes in the collections. It has an even greater interest in connection with the critical study of the Flexibilia, because it represents the culmination of the solid anal structure characterizing its family, in contrast to that of the Taxocrinidae. Its special character is that the interbrachial areas are completely filled by solid plates, suturally united to adjoining rays and to each other, and passing gradually into the tegmen. This is the type which De Koninck and Le Hon had in mind when they expressed the belief (*op. cit.,* p. 119) that in their genus the calyx extends beyond the origin of the arms, although it is not clearly shown by their specimens, and still less indicated now by mine;—which leads to the conclusion that the Belgian species represents only an early and incomplete stage of that type.

This idea is strengthened by a consideration of the stratigraphic position of the respective types. The whole Tournai crinoid fauna as described by De Koninck and Le Hon and as represented in my collection and that of the British Museum, and also the other invertebrate faunas,[1] correlate in a general way with those of the *lowest* part of the American Lower Carboniferous, from and including the Lower Burlington limestone down. They bear a striking resemblance to the Lower Burlington—Kinderhook—Choteau—Waverly—Knobstone faunas as found and studied in Iowa, Missouri, Indiana, Ohio, Kentucky and New Mexico. While the species of the two continents are for the most part different, there is a similarity in the general facies, or assemblage of forms, which is striking not only for what is found, but for what is absent. Not a single one of the crinoid types most characteristic of the Upper Burlington or later formations has ever been found at Tournai; whereas certain types, including the specialized *Mespilocrinus,* that have never passed the Burlington are well represented at the Belgian locality. No competent American paleontologist, finding such an assemblage as the Tournai species of crinoids and blastoids in a locality in this country, would hesitate for a moment to place it below the Upper Burlington.

Now it is a significant fact that the American species described under *Forbesiocrinus* of the type of *F. agassizi,* etc., begin in the Upper Burlington and run upwards, culminating in the Warsaw; not a specimen positively known to belong to that type has been found in any lower formation. On the other hand fragments belonging beyond all question to the same type as my Tournai specimens are now known to occur in the Knobstone of Indiana and Kentucky, and one finely preserved and distinct species comes from the very base of the Lower Carboniferous in northern Ohio. This clearly distinctive geological position, coupled with the decided morphological difference between the two forms, indicates a progression in the interbrachial development of the genus analogous to what has taken place in *Taxocrinus;* with the difference, however, that *Forbesiocrinus* begins at the base of the Lower Carboniferous in about the same stage in which *Taxocrinus* finishes at the close of that epoch.

The first of the new specimens (Pl. XXIII, figs. *1a-e*) is the one referred to by Wachsmuth and Springer in a note concerning *Forbesiocrinus nobilis* (N. A. Crinoidea Camerata, p. 77), and on which we based the opinion that the species was identical with *Onychocrinus.* This was upon the supposition that the rays were free above the first costal, and branched from the fourth distichal in curved armlets like *Onychocrinus.* The last observation is not correct. The specimen is abnormal in the right ramus of the right posterior ray, giving rise at one place to a somewhat *Onychocrinus*-like cluster of branches beyond the first axillary, which, with the apparent freedom of the rays, certainly produces a general appearance much resembling the facies of that genus. But in the left ramus of that ray, and in the other specimen with the arms normal in three rays (fig. 2) as well as in De Koninck and Le Hon s figure *2a,* the bifurcation is almost regularly dichotomous. I corrected the above statement in a paper on the crinoid genera *Sagenocrinus,* etc. (American Geologist, vol. 30, p. 91). This second specimen and a third one, figure 3, confirm the first in showing that the posterior basal is followed by solid anal plates suturally joined to it—thus clearly separating this species from *Onychocrinus* or any other Taxocrinoid. This character determines the affinities of the genus to be with the present family, where it may be considered as a successor of the Silurian *Temnocrinus* with the interbrachial characters of *Sagenocrinus* added in the later American species.

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[1] Herrick, C. L., Bull. Geol. Soc. America, vol. 2, 1891, p. 39.

Instead of having the anal and interbrachial areas completely filled with solid plates forming part of the calyx wall and extending to an apex high up between the rays, which is one of the most characteristic features of the last mentioned series of species, these plates in the Belgian species are limited to the lower part of their respective areas, having their continuous margin somewhat crescentic. By comparing the lateral margins of the rays in specimens of the two types (Pls. XXIII, figs. 1*a, c, d;* XXV, fig. 2; XXI, figs. 1, 2, 3), it will be observed that in *F. agassizi* and *F. saffordi* these interlock with the interbrachial plates by angular faces and perfectly flat surfaces all the way up, producing a zig-zag suture line; whereas in the Belgian form this interlocking ceases at about the angle of $IBr_2$, and from that point upward the lateral margins of the rays are without angles, being longitudinally straight, or slightly rounded toward the transverse sutures.

There is a peculiarity in the mode of attachment of the plates or structures above the level of the interbrachials, which induces a strong desire to see the perisomic plates themselves, which are not preserved in any of the specimens. In *Taxocrinus* and *Onychocrinus* the distal margins of the interbrachials are rounded and smooth, except for slight traces of the attachment of perisome marked by a faint line at the ventral edge of the plates. This line in *Taxocrinus* is shown in figure 6*b* of Plate LVII, and the actual margin of the perisome of *Onychocrinus* in figures 4 and 6 of Plate LXVII. From these it will be seen that there is a considerable space, equal to about the thickness of the plates, between the outer or dorsal surface and the perisome; or, in other words, that the perisome is attached at the inner, or ventral, margin of the interbrachials and lower brachials, and not at their dorsal margin.

In *Forbesiocrinus nobilis,* however, the surface for attachment of perisome begins at the dorsal margin of these plates and extends inward for their full thickness; the distal face of the interbrachials and the lateral face of the lower free brachials is but little rounded, and is covered for its entire depth with strong corrugated ridges, or wrinkles, in a dorso-ventral direction. This is perfectly shown by Plate XXIII, figures 1*a, c, d,* where the lateral margin of the ray is exposed to the third order of brachials, and in still greater detail by the various figures showing these faces upon isolated plates on Plate XXIV, figures 11, 12, 14, 16. The corrugated margin gradually diminishes in thickness until beyond the second bifurcation, where it becomes mingled in the rugosities and longitudinal grooves of the ventral side (see the same figures on Pl. XXIII, and Pl. XXIV, figs. 17, 20, 21, 22). The structure here described may be compared with that of the later forms of the genus in the detailed diagrams on Plate XXI, figures 1, 2, 3.

Now this is an entirely different marginal structure from that prevailing in the calyx below the distal face of the interbrachials; it usually begins at about the middle of $IBr_2$, below which the brachials are connected with the interbrachials, and the latter with one another, by angular faces and straight sutures, with ligaments lodged in deep fossae (Pl. XXIV, figs. 2*b,* 3, 4, 5*a,* 7*c,* 8*c,* 9*b,* 10*c*). In the last figure, 10*c,* the change can be seen to occur on the margin of the same plate. Thus there was at the upper line of the interbrachials an abrupt and complete change in the mode of union, by which there was attached to the interbrachials, and to the inner margins of the rays for some distance up, some kind of a structure which did not consist of solid or suturally joined plates. At first I took it for granted that these were sutural margins for regular interbrachial plates which had dropped out; but the fact that in well preserved specimens no trace of any such plates could be found above the line indicated, and the striking curvature of the distal margin of the interbrachial areas, together with the total absence of angular faces for interlocking plates there or at the margins of the rays above, all negatived this supposition.

A careful study of the markings on many plates showed that this peculiar rugose margin could not be a sutural surface in the usual sense. It is not in a flat plane as we must expect in such parts of sutural surfaces as are apposed; there is a slight curvature in a dorso-ventral direction, and also a gentle rounding of the margins longitudinally, which are in sharp contrast to the condition of the interlocking sutures in *Forbesiocrinus agassizi* and *F. saffordi* (Pl. XXI, figs. 2, 3). There is a slight, but perceptible, projecting rim at the dorsal edge of the plates (Pl. XXIII, fig. 1*d*), and a careful examination of the grooves forming the corrugated surfaces shows that they are rounded, with flowing lines by which in the upper part they connect with, or are merged into, the peculiar longitudinal grooves at the ventral side of the ray (Pl. XXIV, figs. 17*b*, 22). These markings may be profitably compared with those on the margin of the radials in *Pycnosaccus* (Pl. XI, fig. 9*c*) which are definitely known to form the surface for attachment of interbrachial perisome.

It is evident, therefore, that they represent lines of growth of the calcified integument forming the perisome of the upper part of the interbrachial areas, which in this case begins on the outer or dorsal edge of the plates. This produces a structure apparently different from that found in other genera in the thickness of the edge connecting with the perisome, no doubt due to the greater thickness of the perisome itself. We may have a clew to its origin in *Lithocrinus,* which has a similar large first interbrachial followed by other ranges, the plates of which begin to be irregularly isolated by perisome surrounding them. The perisome is on a level with their outer surface, and the imbedded plates are presumably as thick as those which are suturally united; therefore if we could examine the sides of one of them we should expect to find a corrugation for their full thickness. If, instead of being irregularly isolated, some of these interbrachials were definitely arranged so as to form a crescentic line at which the perisome commenced and then filled the remainder of the area up to the tegmen, we should have substantially the structure of *Forbesiocrinus.* Comparison of the figure of *Lithocrinus divaricatus* (Pl. XX, fig. 3*a*) will show that this is not a long or improbable step. Thus the perisome in such forms as these may have been set with thicker plates than usual, deeply imbedded in a ligamentous mass as thick as the corrugated edges of the plates with which it was connected.

This difference in the thickness of the margin is a matter of minor detail. That the structure was of an unsubstantial nature, pertaining to the tegmen rather than to the dorsal cup, there can be not the slightest doubt. It is only necessary to refer to the various figures of *Taxocrinus* on Plates LIII, LV, LVII, LVIII, LIX and LX to show what the general arrangement was. There we have the same crescentic margin of the interbrachial plates, and in figure 3*a* of Plate LVII may be seen the same condition that we would have if the perisome were preserved in our specimens from Tournai. By these the difference in number of interbrachial plates between the new specimens and De Koninck and Le Hon's type, as well as between different areas in the latter, is also explained. Being supplementary plates, forming from time to time to fill up spaces due to the enlargement of the calyx, they vary in different specimens according to age; and they may vary even within the same specimen, as appears in the last mentioned figure 3*a,* which shows 5, 6 and 9 plates in the three exposed interradii. This further appears by the condition of the margins of the axillary primibrach in figures 8 and 9, Pl. XXIII, where in one case the sutural face extends part way up the plate, and in the other all the way; the latter would indicate interbrachials to the height of $IBr_3$, the same as in De Koninck and Le Hon's specimen.

The longitudinal lines on the ventral side of the ray appear upon many of the isolated plates figured, and are very conspicuous on the detached ray in Plate XXIII, figures 1*c*, *d*. The same structure is found in *Taxocrinus* (Pl. LVII, fig. 6*c*), and probably throughout the group generally. It begins with a slight linear indentation of the plates about the upper primibrachs, which runs parallel to the lateral margin, becoming sharper upward and the lines multiplying until there are 6 to 10 sharply bounded grooves; these diminish again distally until in the smaller branches of the ray they are reduced to two and finally to one. There is nothing in these markings to indicate any such thing as a food groove as we find it along the arms in the Camerata and Inadunata, although in some plates the median furrow may be the largest. They seem rather to indicate that in these forms the perisome in the free part of the rays beyond the secundibrachs was firmly attached to the plates by lines of growth, in this manner supporting the ambulacra which in some cases may not have been calcified. The perisome can be seen in place on some plates from the upper part of the ray in *Synerocrinus* (Pl. XLII, fig. 5*b*), and I am unable to distinguish any ambulacra in those places.

In the two principal specimens on Plate XXIII it will be noted that while the two plates following the posterior basal are fairly large, and are perfectly united to it by suture with deep fossae, their distal margin, and that of the small plates interlocking with them, have for the most part the same corrugated surface as already described, indicating the beginning of perisome. This is plainly shown in the plates at the left in figure 1*a*, where the corrugation is seen on the two large plates; it exists also on the corresponding large plates in the specimen of figure 2, although not visible in this figure, while the sutures at the small triangular space at the left, where a plate has fallen out, have deep fossae. The left side of the anal interradius thus had a curved, corrugated edge continuous with that of the adjoining primibrach, the same as in the regular areas; but this is not quite the case to the right where the curve does not seem to connect with the margin of the brachial, but there appears to be a slight curvature in the distal face of the right hand large plate, with one or two small plates next to it, which may have formed the beginning of a tube.

Considering the additional anals at that side in De Koninck and Le Hon's specimen, and the long series of plates bordering the right posterior radial in *F. communis* (Pl. XX, fig. 5*b*), it seems probable that in this form the anal plates to the right passed into a vertical series of varying extent, which, either directly embedded in the perisome or after hugging the right posterior ray to near the level of the tegmen, became the support of an anal tube originating not on the posterior basal, as in all the Taxocrinidae, but at some point above it after the intervention of other solid plates. We have such a case, with still less intervening sutural structure, in the genus *Synerocrinus*, which is about as near the border line of the Taxocrinidae as is possible to imagine. This is probably what happened at some point in the posterior interradius of every Sagenocrinoid, but it did not in most cases result in sufficient differentiation of solid structures to leave the evidence of it in the fossil state. The tendency toward the formation of such a tube is shown perfectly in later species of *Forbesiocrinus*, and the tendency of the tube to lean to the right is found in every group of the Taxocrinidae. This dextral series of anal plates is essentially the same thing seen in *Temnocrinus*, only extending higher up in *Forbesiocrinus communis;* and a comparison of the figures upon Plates XVI and XX is sufficient to show the great general resemblance between the two types.

The morphological position of the earlier *Forbesiocrinus*, therefore, is clearly with the present family by reason of the fundamental anal structure, but with a tendency toward *Taxocrinus* in its interbrachial and higher anal structures. The later species, of which *F. wortheni* may be taken as a typical example, present a type which marks the culmination of the division of the Flexibilia having the strong anal side. This type is the last prominent survivor of the Sagenocrinidae, and in its interbrachial structure might well be taken as the successor of the genus *Sagenocrinus*. The essential difference in anal structure between the two genera may be largely due to the longer posterior basal in *Forbesiocrinus*, which rises to about the height of the radial; so that when it is angular the first large anal plate to the right (which may represent the radianal of the earlier form) is *above* the radial instead of below it.

The two earliest species of this type come from the Upper Burlington limestone, no example of it being known from the rich and abundant crinoidal deposits of the Lower Burlington or Kinderhook or their equivalents. One of these Upper Burlington species (the only one in the genus) has only two primibrachs—the celebrated and splendid *Forbesiocrinus agassizi,* always considered the rarest prize of the Burlington collectors, and one of the most magnificent known species of the Crinoidea Flexibilia. It is essentially a *Sagenocrinus* minus the radianal, with an elongate posterior basal and a proximal enlargement of the stem. What the line of succession was through the Devonian we do not know; the geological record is silent as to that; but it is evident that the increase in the number of primibrachs which went on in this family from the Silurian to the Carboniferous parallel with the Taxocrinidae was practically accomplished in this genus as we first find it. For alongside of *F. agassizi* in the same beds there is a species persistently differing from it in size, in which the three primibrachs characterizing the final stage of the genus are constant; and throughout the abundant Keokuk species, up to the conspicuous forms which mark its extinction in the Warsaw, there is no departure from this character. Therefore, whether we consider *F. agassizi* as a case of retarded development or of retrogression, it is clearly such an exception as may be recognized without impairing the generic unity.

This genus affords the material for a very interesting study of the articulations and unions by which the plates of the calyx are connected, and by which the flexible character which marks the whole group is beautifully illustrated. I have for many years past secured all the loose plates of Flexible crinoids that have been found by the collectors at Tournai, where the fossils are often much disintegrated, falling to pieces when dislodged from the soft matrix; while unfavorable for the production of complete specimens, this results in furnishing many isolated plates with the surfaces perfectly exposed by weathering. We thus obtain material for the study of articulating surfaces far better than is found in most American localities, where specimens intact are much more abundant. Nearly all of these plates belong to species of this genus, as is shown by the character of the lateral faces; a very few are referable to *Taxocrinus,* of which one complete specimen has been found.

In the Tournai species of this genus there are five kinds of articulations or unions between the plates, which are fully illustrated by the various figures on Plate XXIV:

1. Between infrabasals and the proximal or upper columnal. This is by short ligaments and finely striated contact areas, like that between any two-stem ossicles. I have not a specimen to illustrate it in this genus, but from the appearance of the stem and attached infrabasals in Plate XXIII, figure 3, I assume it to be the same as in many other Sagenocrinidae and *Taxocrinidae,* being a close suture like a stem syzygy, much firmer than those between succeeding plates, thus causing the infrabasals to adhere usually to the stem when the specimen is disintegrated.

2. Between infrabasals and basals; basals and radials; radials with each other and with interbrachials; interbrachials among themselves and with primibrachs up to the angle of $IBr_2$. This is a non-muscular union by connective tissue or ligament; there is a fine border of fine interlocking crenulation, inside of which is a deeply sunken fossa occupying a large part of each face of the plate, evidently for the lodgment of very large and powerful ligaments or elastic tissue. On these faces only a small portion of the apposed surfaces of the plates is in close contact, being confined to that marked by the crenulated border, while the main connection is by means of a large mass of soft parts, affording the most perfect example of that flexible character of the calyx walls which in various degrees—probably in some forms almost lost—characterizes the whole group (Pl. XXIV, figs. 1*a, b, 2b,* 3, 5*a, b, 7c, 8c, 28c*). It will be noted that this is also the mode of union between the posterior basal and the succeeding anal plates (Pls. XXIII, fig. 3; and XXIV, fig. 4).

3. Between radials and primibrachs. This is a peculiar kind of union which may be said to be a modification of the last, producing an imperfect muscular, or perhaps only ligamentous, articulation; there is a large dorsal ligament, and a single large ventral fossa which may have been occupied by muscle, though more probably by a more or less ligamentous mass. It differs from the succeeding muscular articulations in being unpaired (Pls. XXIII, figs. 12, 13; XXIV, figs. *7b*, *8a*, *28b*). This peculiar single character has a suggestive bearing upon the possible nature and origin of the radial plate. If it were in the right posterior ray of *Temnocrinus* or any other genus having a radianal in primitive position at the base of the ray, we should at once recognize in this lowest plate the lower half of a compound radial—the infer-radial—and would not call it, but the next one above it, the true radial. We may have the same thing here only extended into all five rays,—for every radial I have found has the same unpaired distal face. Therefore the evolution of *Forbesiocrinus* from *Temnocrinus*, by which the two primibrachs of the latter became what we have been calling three in the former, may have been accomplished by the insertion of an infer-radial in the four regular rays, thus making the radial in all five rays compound. In other words, the process of equalizing the rays in this case would be not by the elimination of the radianal of the Silurian type, but by the addition of its equivalent to the other rays; that is, the increase of primary plates in the ray would be by interpolation at the base, and not by addition at the distal end.

We have a similar but more complete case in the Taxocrinidae, where the Ordovician and Silurian *Protaxocrinus*, with a radianal at the foot of the right posterior ray and two primibrachs all around, is modified in the Devonian and Carboniferous first by elimination of the radianal, producing *Eutaxocrinus* with only two primibrachs, and then by the addition of a primary plate in the regular rays, resulting in *Taxocrinus* with three primibrachs. It may be that every increase in the primary plates of the ray was by interpolation above the basals, in which case only the two upper ones—the axillary and the one next below it—would be strictly brachials, homologous to the two primibrachs of the primitive crinoid. Nevertheless, as it is only by a fortunate chance that we can observe the articulations of these parts in two or three genera, and in most of them it must always remain unknown, the evidence is not deemed sufficient to warrant a modification of descriptive terms to meet such a theory.

4. Between successive brachials throughout the ray, from $IBr_1$ up. This is a paired ligamentous articulation, with transverse ridge, dorsal ligament fossa, and two broad ligament fossae lodging bundles of elastic ligament on either side of a vertical ridge—a modified articulation comparable to the articulation on the radials in the Recent crinoids; except that here the fossae for attachment of muscles are too much reduced to be apparent in the fossil.

5. Between distal margin of interbrachials and connecting lateral margin of brachials and the interbrachial perisome already mentioned; consisting of vertical corrugations on the edges of these plates for almost their full thickness at first, but gradually shortening upward and disappearing at about the end of the third order of brachials. There are no pits or fossae, and the lateral faces of the plates are not angular for meeting interlocking plates, as they are below where union No. 2 prevails. The change in mode of union usually occurs on the primibrach next to the axillary, $IBr_2$, and it may be studied in detail in the figures on Plate XXIV. There it will be seen that union No. 2 extends from the base to the angle on $IBr_2$ (figs. *7c*, *8c*, *10c*); No. 5 begins on the upper half of the last mentioned plate (fig. *10c*) and continues upward, being shown on axillary $IBr_3$ (figs. *11b*, *12b*); $IIBr_1$ (fig. 14); $IIBr_2$ (fig. 16); and $IIIBr_2$ or $IIIBr_3$ (figs. 21, 22). It may also be seen along the margin of the right anterior ray in Plate XXIII, figure *1d*. From these and other specimens there has been constructed the lateral view of the ray margins shown on Plate XXI, figure 1, where the full extent and relations of the two kinds of union may be seen. It will be further noted that while the lower interbrachials are joined among themselves by union No. 2 (see proximal

and distal views of first iBr, Pl. XXIV, figs. 5*a, b*), No. 5 sets in among these plates at the same level as on the brachials (see distal view of $iBr_2$, Pl. XXIV, fig. 6 and Pl. XXI, fig. 1).

By giving attention to the articulations or sutural markings at the sides, one can identify the position in the ray of any isolated plate from the radial to the axillary primibrach, and approximately that of those of the second and third orders. A number of these are shown in their proper succession on Plate XXIV, but it must be remembered that they are not from the same individual, having been collected at random in the debris; therefore they are relatively disproportionate in size. In the same way from isolated plates found at an equivalent horizon at Button Mould Knob, Kentucky, I have reconstructed part of a ray shown in figures 11*a, b* on Plate XXIII, proving the existence here of a species essentially similar to *F. nobilis.*

In *Forbesiocrinus agassizi* from the Upper Burlington limestone the brachio-interbrachial union is a modification of No. 2; there is a crenulated margin inclosing a large fossa, which is not continuous but is broken up by a number of small facets within it (Pl. XXV, figs. 3*c*, 5*f*, 6*e*); and this continues to the higher brachials, where the interbrachials by gradual diminution in size merge into the perisome (Pl. XXI, fig. 2). The same (unpaired) articulation is found on the distal face of the radial (Pl. XXV, fig. 5*e*), which does not agree with the theory above suggested of the homology of the last two primibrachs. The compound radial having disappeared in *F. agassizi* (which has only 2 IBr), the articulation on the distal face of R ought to be regularly double. We also find an imperfect articulation in this species at the distal face of the axillary $IBr_3$ and proximal face of $IIBr_1$, which was an immovable plate suturally united to its fellow in the pair.

The surfaces of articulation and union in the later species of this genus, with their more solid interbrachial structures, are also somewhat different in detail from those of *Forbesiocrinus nobilis.* In the brachio-interbrachial union the fossae are interrupted by several small facets for apposition of the solid surfaces; that is, there was more attachment of calcareous parts and less of ligamentous masses and therefore the calyx was less pliable. The muscular articulations are also not so well defined (see Pl. XXV, figs. 5*e*, 6*d*). In *Forbesiocrinus saffordi,* a very large species marking the culmination of the genus at the close of the Warsaw epoch, the loose articulation, No. 2, is not found, but the mode of union from the basals up was by means of interrupted grooves and ridges, and small modified fossae (Pl. XXXI, fig. 6*c*). There was still further diminution of mobility in this species by reduction in size of the ligament fossae and increase of the facets for attachment of calcareous surfaces (Pl. XXXI, figs. 7*b, c, e*, 10*b*). Yet this is a matter of minor detail, the difference in plan not being great.

In *Forbesiocrinus nobilis* we can see the remnant of a dorsal nerve canal in the arms, which is found in but few of the genera. It is shown in the articular face of many brachials in the form of a median groove running from the ventral side to the point within the plate where the dorsal canal should be, often becoming a distinct cavity (Pl. XXIV, figs. 10*a, b*).

The foregoing description and discussion has been based entirely upon specimens of the Belgian species from Tournai. It is now interesting to note that a form remarkably similar to it has been identified from isolated plates in various localities in America at the equivalent horizon, viz., the base of the Lower Carboniferous. At several places in the Knobstone of southern Indiana and Kentucky these plates have been found bearing the same tuberculous ornamentation, and showing the same peculiar articulations. From perfectly weathered specimens I have been able to reconstruct part of a ray from the radial to the axillary IBr, with the plates in their proper relative position as determined by the character of the lateral faces (Pl. XXIII, figs. 11*a, b*). Here can be seen the sutures with deep fossae for the interlocking of the interbrachials up to the middle of the $IBr_2$ where the corrugated margin for attachment of less solid structures sets in. Distal and proximal faces of a radial and primibrach are also shown (figs. 12, 13). Similar plates have been found in equivalent strata at Fern Glen, Missouri (fig. 9), and at Lake Valley, New Mexico (Pl. XXIV, figs. 28, 29).

Unfortunately at none of these localities have we been able to recover any part of the calyx intact; but from a locality in northern Ohio of corresponding stratigraphic position we have a finely preserved species, the *Forbesiocrinus communis* of Hall, from the base of the Waverly at Richfield (Pl. XX, figs. 4-8). This is thoroughly distinct from the fragments at other American localities as to surface ornament, and from the Belgian species in other ways, showing a considerable modification of characters, especially in the smaller interbrachial system and the distinct extension of a series of anal plates to the probable limit of the tegmen. It is possible that if we had specimens of the Belgian form better preserved in the original matrix we might find a slight extension of the anal series to the right, but it could not have gone far, as there are no angles for sutural attachment at the margin of the ray in the specimens we have. We should, however, expect individual variation in this respect.

Taking the two species together, it is easy to see that the geologically antecedent form to which the genus is nearest related is *Temnocrinus,* of which it may well be a direct successor. The development would be the same as from *Protaxocrinus* to *Taxocrinus,* producing an equalization of the rays to three primibrachs all around. With this one change, the two forms would fall readily under the same generic definition.

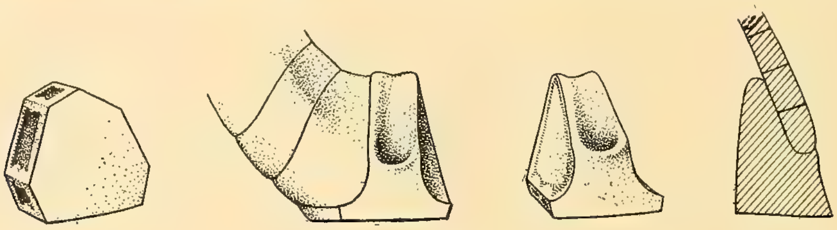
Returning now to the first of the questions stated for discussion at the outset—the relations of this genus with *Taxocrinus*—it may be said here briefly that the two genera represent the two diverging lines in the development of the anal structures of the Flexibilia, and are therefore fundamentally distinct: *Forbesiocrinus* the stronger type of structure, in which the posterior basal is followed by plates united to it and to adjacent rays by suture; *Taxocrinus* the weaker, in which the posterior basal supports an anal tube bordered on one or both sides by perisome. In the earlier type represented by the Belgian species, with the presence of an anal series probably passing into a tube not originating on the posterior basal but at a variable height above it, we have a stage somewhat intermediate between the extremes of the families Sagenocrinidae and Taxocrinidae. With the wide divergence of its free rays, not bounded by solid plates except at the lower part, it would represent in the former family the tendency that *Onychocrinus* does in the latter.

In the later type, containing the most numerous and prolific species, the genus represents the culmination of its family not only in time but in structure, as *Taxocrinus* and *Onychocrinus* do in theirs. Here the calyx wall is extended by the growth of solid plates in the anal and interbrachial areas until they are completely filled, and these plates merge gradually into the tegmen; and in this respect we have such a complete contrast with the last mentioned genera as the typical representatives of their family, that a more detailed discussion of their respective characters will be instructive. It is the more so on account of the confusion long existing between this genus and *Taxocrinus,* and the frequent shifting of species from one to the other; the comparison will therefore be made chiefly with *Taxocrinus,* with appropriate reference to *Onychocrinus* in cases where the identical structures are better represented.

The fundamental distinction between the two types, as already indicated, is to be found in the construction of the posterior basal and in the anal area, and as to the later species in the interbrachial areas:

1. The posterior basal and anal area. In *Forbesiocrinus* the posterior basal is elongated and supports a succession of plates of more than one series which form a solid part of the calyx wall; it is of uniform thickness throughout, is angular or truncate above, and is connected with succeeding plates to the full thickness of its distal face by the same kind of articulation or union as it is to the other adjacent plates. Except for its usually much larger

size, it bears the same relation to the plates above it that the first interbrachial does in the regular areas. Its form, and the mode of union on its lateral and distal faces, are shown by text-figure 27, and on Plate XXIII, figure 3.



27 28a 28b 28c

Figs. 27, 28*a-c*

FORMS OF POSTERIOR BASAL

In *Forbesiocrinus:* 27, showing angular distal face, and mode of union. In *Taxocrinus:* 28*a*, showing rounded socket for anal tube, with curved brachials adjoining at one side; 28*b*, oblique view of same, showing how the plate slopes to a thin, rounded distal margin, without surface for sutural attachment; 28*c*, dorso-ventral section of same with base of tube in place.

In most of the species the posterior basal is angular with unequal distal faces, and supports two anal plates; but in some of the later Keokuk or Warsaw species we find it truncate, with another plate interpolated below the two.

In a typical *Taxocrinus*, on the other hand, while the posterior basal is a very long plate, only about half of it is visible from the exterior, where the apparent upper margin is indented by a socket for the reception of plates of the anal tube. I formerly supposed this indentation to be actually in the upper margin of the plate, but some fortunate preparations of specimens of this genus and *Onychocrinus* have demonstrated that this is ordinarily not the case. The plate rises above it and behind the tube plates, sloping toward the interior for a distance often as great as, or greater than, the visible portion. The so-called socket is only the lower part of a shallow, median depression extending over the distal edge of the plate to the interior. The posterior basal thins to a narrow, rounded upper edge which is smooth, and is not articulated to any succeeding plates, but forms a margin for the attachment of the finely plated flexible perisome of the tegmen. The form of the plate and of the tube resting on it, now for the first time ascertained, are shown by the text-figures 28*a-c*, which are made after careful study of a number of specimens dissected to bring out these parts. Some of these are figured on Plate LVII, figures 4, 5, 6*a*, 8*b*, which show exactly the form and relations of both plate and tube in the actual specimens. And in the various figures of *Onychocrinus* on Plate LXVII may be seen how the perisome is joined to the basal, the tube, and the adjacent brachials.

As the specimens are ordinarily found we see only the lower half of the basal, which appears short, curved or indented above. The upper half is concealed by the anal tube, which rests in the depression and socket (Pl. LVII, fig. 2). This may lie rarely in the middle, in which case the posterior basal would be symmetric; or it may lie structurally to the right side; or it may be displaced by pressure, and thus pushed to one side. In most cases the plate appears unsymmetric, with the right upper corner lower than the left. Its general outline in a front view is elongate, rising high between the radials, with nearly parallel sides above, and curving slightly outward below to meet the abutting basals. The upper face terminates in a thin, rounded margin, having no plane surface for the attachment of plates. This margin has a shallow median depression, which follows the sloping exterior surface of the plate to a socket about half way down. The notch, or socket, is a mere support for the anal tube, which rests in the socket and groove, usually to the extent of the first two joints. Whether it rests exactly in the middle or to the left or right of it determines the outline of the posterior basal as usually seen in the fossil from the exterior. As the tube, in common with all anal structures, for some unknown reason tends toward the right, it usually leans in that direction, leaving the visible shoulder of the basal to the left the largest. The structure of the tube itself will be more appropriately given under *Taxocrinus* and *Onychocrinus;* it is sufficient here to say that it passes up to the tegmen, and is bordered by perisome extending on either side to the brachial series to which, as well as to the posterior basal, this connecting perisome is attached, not by angular or straight faces but by smooth and rounded margins. The general relation of the anal tube to the tegmen and the posterior brachial series in *Taxocrinus* is perfectly shown in *T. intermedius* (Pl. LIII, figs. 1*a*, *b*), and in *Onychocrinus* by the various figures on Plate LXVII.

The general form and character of the posterior basal as above described prevails generally in the family Taxocrinidae, and it is the morphological feature determining the structure on which the family is to a large extent based. It may not always be so regular as in *Taxocrinus,* and in some forms the tube socket is relatively higher, and may even be at the upper margin; this is the case, for example, in *Synerocrinus,* where the lower plate of the tube is joined to the truncate end of the basal, and for part of its length to the brachials, on account of which the genus is separated from the family. The two types of structure of the posterior basal are thus absolutely and fundamentally different, and cannot be mistaken for one another, although the condition of preservation of the fossils sometimes renders it difficult to interpret them with certainty. The only question need be, is the posterior basal suturally connected with the succeeding plates, no matter how narrow the posterior area, or how few or many plates are in it? If not so connected, it is of the *Taxocrinus* type. This correlates with the test heretofore given, viz., the presence or absence of sutural connection between the anal plate and adjacent brachials.

As a necessary result of these structures the fact follows, often very important in practice, that the margins of the posterior rays bordering the anal interradius show marked and constant differences in the two genera. In *Forbesiocrinus* these lateral faces of the brachials are flat surfaces, marked to their full depth with either fossae and crenulated margins and facets for connective tissue, or with interlocking grooves and ridges in a dorso-ventral direction for similar connection (Pl. XXI, figs. 1, 2, 3). They are angular all the way up in the *wortheni* type, and part way up in the *nobilis* type, interlocking by sutural attachment with solid interbrachial plates as thick as the margin of the brachial series. In other words, the structure at the margin of the posterior interradius is the same as in all the regular interradii. In *Taxocrinus* the structure of these margins is entirely different from that in the other areas; the lateral faces of the brachials are rounded and perfectly smooth, without any kind of fossae, crenulation or rugosity for the attachment of plates, and the border of the rays forms a straight line (Pls. XXI, fig. 4; LVII, figs. 4, 8*a*, *b*). They are adapted to the attachment of finely plated perisome at their ventral margins, for which there is a slight linear depression, but not of solid plates (Pl. LVII, fig. 6*b*). Upon this character, for instance, the type of Phillips's *Taxocrinus nobilis* (Pl. LIV, fig. 1*a* and especially fig. 1*b*) can be readily distinguished from *Forbesiocrinus nobilis* with which it has been so much confounded in the literature. If in any specimen the lateral margin of the rays bordering the anal interradius, or of only one of them from the posterior basal up, is smooth and rounded, without any indication of sutural attachment of plates, it does not belong to *Forbesiocrinus* or any genus of the Sagenocrinidae.

2. Correlated with these differences between the two genera in the structure of the posterior basal, there is also a difference in the disposition of the interbrachial plates. In *Forbesiocrinus* of the *wortheni* type these tend to fill up the spaces between the rays and their divisions, running nearly to an apex, gradually diminishing in size and passing without any abrupt line of demarcation into the tegmen (see various figures on Pls. XXVII-XXIX). They thus form lanceolate areas more or less filled with plates suturally connected with the

brachials. In *Taxocrinus* this sutural connection extends for a relatively much shorter distance (rarely above $IIBr_2$) upward; and the interbrachials, instead of running to an apex tend to spread out, ending in a crescentic distal margin of fairly good-sized plates, rising at either end to meet the rays (Pl. LIII, figs. 2-5, and various figures on Pls. LVIII, LIX). This distal margin is smooth and rounded for the attachment of perisome (Pl. LVII, figs. 8*a*, *b*), leaving no place for further suturally connected plates; and in this respect the difference applies to the *F. nobilis* type as well. This distinction becomes important in cases like *Taxocrinus giddingei* and *T. ungula,* in which the perisome bordering the anal tube has developed into rather large plates, so as to strongly resemble the posterior structure of *Forbesiocrinus;* the form of the interbrachial areas determines their generic position.

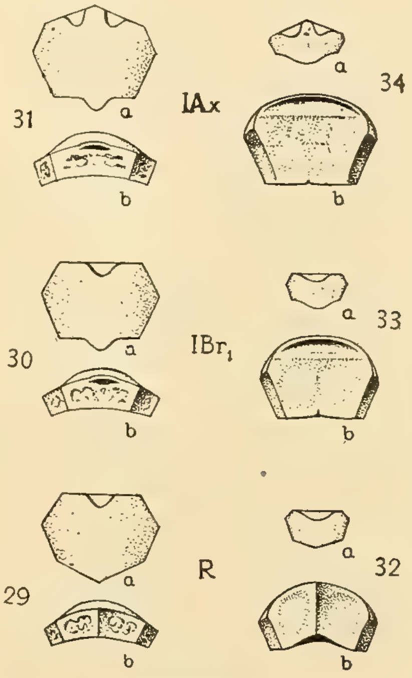
*Forbesiocrinus* is characterized by a great profusion of interbrachial plates; while in *Taxocrinus,* although not always absent as supposed by De Koninck and Le Hon in proposing *Forbesiocrinus,* they vary greatly among species from few, or perhaps none, to such abundance as is seen in *T. whitfieldi, T. colletti, T. ungula, T. giddingei,* etc., which on account of the profuse development of these plates have a considerable superficial resemblance to the later *Forbesiocrinus.* In both genera the matter of age must always be considered—the interbrachials being supplementary plates developed to fill up spaces in the growing crinoid, so that a young individual of these same species may have scarcely any of them (Pls. XXVIII, LV, LVI, LVIII).

Transition forms showing intermediate stages of the two structures are to be expected. The two species last mentioned are good examples of them from the *Taxocrinus* side, especially *T. ungula* with its rounded anal series imbedded in good-sized plates extending to the rays on either side (Pl. LV, figs. 3, 4, 6, 7); and the bordering plates are even more developed in the diminutive *T. giddingei* (Pl. LIX, figs. 2, 3). In these species, and others exhibiting to a lesser degree a tendency toward the *Forbesiocrinus* anal structure, the growth of definite plates along the tube always begins at the right side, never at the left; and in specimens where this growth extends the farthest it is always considerably short of completion on the left side, the left posterior ray being connected by plates for only a short distance. In none of such cases have I seen a complete development of these plates to the top of the area on both sides, as in the *Forbesiocrinus wortheni* type. In these forms also the tube-facet lies nearer the upper margin of the basal than in those where I have described it, and its tendency is always toward the right upper corner. Doubtless if we could see the exact form of the plates in some of these examples we should find a tendency to sutural connection at the distal face of the basal, as we actually do in *Synerocrinus.* But a careful inspection of the figures, and better still of the specimens themselves, gives a clear impression that these are only overgrown perisome plates, lacking the definite arrangement and solid appearance of those in the other areas.

On the other hand, in some otherwise typical *Forbesiocrinus, e. g., F. multibrachiatus,* there is a tendency toward an arrangement of plates in a vertical series which, though bordered on either side by perfectly solid plates, often develop a line of weakness by which the series sometimes becomes partially detached along its left margin (Pls. XXVI, fig. 5; XXVII, fig. 2; XXVIII, figs. 4, 5). These cases have hitherto added to the confusion between the two genera, and some of the species have been shifted from one to the other repeatedly. With our present understanding there is not much practical difficulty in assigning them satisfactorily, the form of the interbrachial areas as above described assisting materially, especially in questions arising among the later Lower Carboniferous species, where the chief conflict may arise.

In addition to the foregoing points of difference there is another of some importance in the size of the visceral cavity, as shown by the relative massiveness of the calyx wall. There is in both genera a gradual increase in thickness from the radials to the axillary primibrach; thence it continues about the same to the tertibrachs, beyond which the plates gradually become thinner; from the last level upward there is little difference between the two genera, but below it the plates of *Forbesiocrinus* are generally only about half as thick proportionally as those of *Taxocrinus*. The best mode of expressing this is in the ratio of width of the plates—representing the circumference of the calyx—to their thickness. The average of measurements of several radials and axillary primibrachs of *Forbesiocrinus nobilis* and *agassizi* in which the relative dimensions are similar, compared with *Taxocrinus colletti*, shows the following ratios of width to thickness:

*Forbesiocrinus*..... R: 1 to 0.3; 1Ax: 1 to 0.47
*Taxocrinus*........ " 1 to 0.6; " 1 to 0.75



FIGS. 29-34

Showing relative thickness of calyx plates; Radial (R), first ($IBr_1$) and third (IAx) primibrachs in natural order from bottom up; *a*, dorsal view; *b*, proximal view; 29, 30, 31, *Forbesiocrinus nobilis*, all natural size; 32, 33, 34, *Taxocrinus colletti*; *a, a, a,* natural size; *b, b, b,* enlarged to same size as corresponding plates of *Forbesiocrinus*.

These relations may be better shown by the following series of figures made from the radial and two primibrachs of *F. nobilis* and *T. colletti*, giving the dorsal outline together with a proximal view showing the full thickness of the plates. Those of *F. nobilis* are natural size; in the *Taxocrinus* the dorsal outline is natural size, while to facilitate comparison the proximal view is drawn to the scale of the *Forbesiocrinus* plates. In this way the great difference between them can be readily seen. The relative thickness of the plates in these forms as far as the highest tertibrach may be seen in the figures on Plate XXI, figures 1, 2, 4; *F. saffordi* (fig. 3) being exceptional. This fact is of some practical importance, as it will often facilitate identification of the genera from fragmentary specimens, or even isolated plates.

*Forbesiocrinus* exhibits an extreme development of the sinuous articulation in the brachial series which has given rise to the idea of "patelloid plates" (see Pls. XXII-XXIX). There is a large curved indentation at the middle of the distal margin of each brachial, corresponding to a projection or process from the proximal margin of the succeeding plate, which in a moderately extended position of the ray perfectly fits and fills it. Where the two are in that condition the suture line between the plates, as visible externally, has a double curve from the middle each way, producing a "wavy," "sinuous," or "arcuate" outline (Pl. XXIV, fig. 17*a*). This was observed by De Koninck and Le Hon, and carefully noted in their generic description of *Forbesiocrinus*. They thought it a remarkable structure, such as had never been observed in any other genus of crinoids. Hall (Geology of Iowa, vol. 1, pt. 2, p. 630) described and figured it more fully from a specimen of *F. agassizi*, in which it is especially conspicuous, commenting as follows:

> The indentation on the upper margin does not extend throughout the thickness of the plate, but only to a very moderate depth, and is filled by a superficial plate which is separately articulated and sometimes anchylosed to the outer margin of the plate above, and lying over the suture below, somewhat like the patella of the knee-joint. This patelloid plate is sometimes large. In many instances there is no suture-line visible at the junction of the small patelloid plate with the next above; while in others, the suture is

clearly visible, proving it a part of the structure. Had it been otherwise, this thin projecting plate, so far overlapping the plate below, would have prevented all motion in a direction outwards; and since this structure extended into the arms, we should expect to find there the means of free movement among the plates.

This description is fairly correct as to the facts; the only fault to be found is with their interpretation. That the indentation does not extend through the plate is important, and is clearly proved by the form of the suture at the ventral side (Pl. XXIV, fig. 17*b*) where it is a straight line without any trace of sinuosity. But, instead of this projecting process being "separately articulated and sometimes anchylosed," the fact is just the reverse. The projection is a mere extension of the dorsal side of the upper plate from its proximal face, thin, fragile, and tapering from its origin to a still thinner outer edge; and it is sometimes broken transversely from strain at death or during fossilization, so as to give the appearance of a separate plate. This has already been fully explained in the chapter on Morphology.

Hall's idea of "patelloid plates" was accepted by subsequent authors generally, including Wachsmuth and Springer (Rev. Pal., pt. 1, p. 51)., and Bather (Lankester's Zoology, pt. 3, p. 190). Miller and Gurley dissented (Bull. 3, Illinois St. Mus., 1894, p. 47), saying that "the tooth-like projection, in *Forbesiocrinus agassizi,* is not a separate plate; there are no patelloid plates in any species of *Forbesiocrinus*"—a correct observation for which they are entitled to due credit.

Such "patelloid" processes, or arcuate sutures, are not confined to *Forbesiocrinus,* but are widely prevalent throughout the whole group, and are especially strong in *Taxocrinus,* from specimens of which we have interesting illustrations of their structure. Plate LVII, especially figure 9, shows the presence of processes and arcuate sutures in some parts along with perfectly straight sutures in other parts of the same specimen, where slightly worn by weathering.

The stem of *Forbesiocrinus* is of the proximally enlarging type, similar to that of *Taxocrinus* and many of its allies. It differs in this from *Sagenocrinus* and *Lithocrinus,* two of its Silurian predecessors, but agrees with *Temnocrinus.* The stem is large, and has been found incomplete to the length of 12 inches. The enlarged proximal columnals are extremely thin in proportion to their diameter, as may be seen in the figures of *F. saffordi* (Pls. XXX, fig. 16; XXXI, figs. 4*a,* 9), and very strongly crenulated. The union between the proximal columnal and infrabasals was stronger than that between infrabasals and basals, or succeeding connections, as already explained. The excess of organic matter in the latter would cause this connection to give way first in fossilization, and therefore in disintegrated calices we often find the infrabasals adhering to the top of the stem. When the stem breaks off it is usually at one or more joints distant from the calyx, the top columnal remaining attached; so that we scarcely ever in this genus see the inferior surface of the infrabasals. This is well shown in Plate XXX, figure 5*a,* where the proximal ossicle is attached to the base, but is so thin that the infrabasal sutures show through it.

I cannot see in the facts now known sufficient evidence to sustain the theory that the top columnal is a persistent proximale, and that new columnals were formed below it and not next to the calyx as in the existing crinoids. The union of this upper columnal with the infrabasals, while of the same type as that between columnals generally, may have been a little stronger on account of its extreme thinness, and probably became practically a fusion in many mature specimens where the interpolation of new ossicles had ceased. For discussion of this point see the chapter on Morphology.

*Forbesiocrinus* presents a singular case of divergence from the general rule regarding the position of the small infrabasal. In a large number of detached bases of *F. saffordi* showing the inner surface of the infrabasals, the small plate with but few exceptions is located at the anterior instead of the right posterior as is usual in the Flexibilia. This is also the case in several specimens of *F. multibrachiatus,* but in other species in which these plates can be observed their position appears to be normal. The specimens of *F. saffordi* have thrown important light upon the structures at the inner floor of the calyx, and the orientation of the axial opening leading into the stem; there are about 25 of them, all thoroughly weathered out of the soft matrix, so that the original surfaces are well exposed. At the inner floor of the infrabasals the axial opening is surrounded by a thin partition which arises and expands into a funnel-shaped vessel with three rounded lobes coinciding in position with the infrabasals, each having a broad, shallow chamber leading down toward the central opening (see various figures on Plate XXX). The lobe upon the small infrabasal is of course radial; while the other two, whose chambers pass in over the edges of the larger infrabasals, are interradial. The stem lumen is quinquepartite, usually dividing into five strongly petaloid lobes a short distance down.

In order that the chambers of the three lobes of the funnel shall produce five channels in the stem, two of them must be subdivided, and one would naturally expect that these would be the two on the larger plates; but that is not what happens. The lobe on the radially situated infrabasal divides by means of a thin median septum into two chambers, which encroach somewhat upon the other two lobes and pass down to an interradial position; on one of the others the chamber, already interradial, remains single and passes directly down, while the third, also interradial, is likewise divided by a septum, one branch remaining in its original position and the other diverging to the fifth, and before unoccupied, interradial side (Pl. XXX, figs. 3*c*, 5*c*, 6*c*, 7*b*, and text-fig. 2*a*[1]). Thus within the three lobes five smaller channels are produced, all interradial, and they pass down into the stem in that position; they are at first not equal—the three opposite the infrabasal sutures being the largest, and the other two considerably smaller (figs. 3*a*, 5*a*, *c*), but after passing into the stem they soon become equal (figs. 6*a*, 9, 14). In *F. agassizi* the canals at a short distance below the calyx appear to be generally interradial, although the orientation is indefinite in some specimens, and this is probably the condition throughout the genus.

The further taxonomic and nomenclatorial questions involving the relations of this genus to *Taxocrinus* are complicated and difficult, and it will be necessary to state them at some length in order to reach a conclusion which may seem fair:

It has already been stated that De Koninck and Le Hon founded *Forbesiocrinus* upon a form which they fully described and illustrated, but erroneously identified as *Taxocrinus nobilis* of Phillips. In justifying their proposal of a new genus upon a supposedly already described species, they undertook to limit *Taxocrinus* "to those species which do not possess interradials (interbrachials) but of which the calyx consists exclusively of basals, or of those and the first radial pieces, such as *T. macrodactylus* Phillips, and *T.* (*Cyathocrinus*) *Rhenanus* F. Roemer" (Recherch. Crin. Carb. Belgique, pp. 120, 121). This was not a very happy suggestion, for not only does *T. macrodactylus*, one of the species cited by them, have at least one interbrachial, but Phillips had included in his genus two other species not mentioned by De Koninck and Le Hon which have it likewise. Therefore on this character, upon which De Koninck and Le Hon chiefly relied, the separation of the new genus could not be upheld. Phillips did not so limit his genus, as is evidenced by the species he ranged under it; and M'Coy in redescribing it in 1854 (British Pal. Fossils, p. 53), definitely specified as a generic character under *Taxocrinus*, that "five hexagonal interradial plates intervene between the second primary radials"; and he laid stress on this, adding, "the interradial plates and the separation of the primary radial rows seem to separate this genus from *Ichthyocrinus*."

In 1865 Meek and Worthen (Proc. Acad. Nat. Sci. Philadelphia, p. 138) discussed at length "the genus *Taxocrinus* and its relations to *Forbesiocrinus*." They found the same objection as above stated to De Koninck and Le Hon's definition, and concluded that the only difference between the two then ascertainable was in the *number* of interradials, and not in

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[1] P. 35.

their presence or absence; and that "if *Forbesiocrinus* is to be retained as a distinct genus from *Taxocrinus,* it will have to be separated upon some characters or differences not yet observed." But they proposed to continue to use the two names—*Forbesiocrinus* in a subgeneric sense—for the sake of convenience, ranging under *Taxocrinus* species without interradial or anal pieces as well as those with one or two each, and under *Forbesiocrinus* those with a greater number of such pieces. In 1871, Professor Beyrich (Monatsber. K. preuss. Akad. Wiss., Berlin, Feb., p. 43) expressed the opinion that the separation of the two genera could only be maintained if *Taxocrinus* were limited to those species in which the first division of the radii takes place in the third joint, while four primary radial segments are characteristic of *Forbesiocrinus.* This would exclude nearly all the Carboniferous *Taxocrini,* among them the most typical species of Phillips.

In 1878 Wachsmuth and Springer (Proc. Acad. Nat. Sci. Philadelphia, p. 254), discussing the relations between the two genera in connection with the new form *"Ichthyocrinus" nobilis,* doubted whether they could be separated, even subgenerically. But in 1879 (Rev. Pal., pt. 1, p. 43) we reviewed the subject at some length, and pointed out the fact that in the forms considered to be *Taxocrinus,* being species with but few interradials, the anal plate had a truncated upper margin and was succeeded by from two to six similar, narrow, quadrangular plates longitudinally arranged; that these formed the dorsal side of a short and slender lateral proboscis whose ventral parts, as well as the wall supporting them, had never been found preserved, and evidently consisted of more fragile material; and further that among the species referred to *Taxocrinus* were not only those with few or no interradials but some with a comparatively large number. And we concluded that while on the anterior side of the latter specimens the construction seemed almost identical with that of *Forbesiocrinus,* "their posterior aspect exhibits in *Taxocrinus* a small lateral proboscis, while in *Forbesiocrinus* the space is filled with heavy plates; in the latter an almost pentamerous symmetry, in *Taxocrinus* . . . . a distinct bilateral one. This we consider the best distinction between the two genera" (*ibid.,* p. 47).

Von Zittel recognized the genus, both in his Handbuch, 1879, and in the Grundzüge, 1895; and in Zittel-Eastman's Text-book, 1896, following the above conclusion of Wachsmuth and Springer, it was stated (p. 164) to differ from *Taxocrinus* in the construction of the anal area. In the North American Crinoidea Camerata, 1897, however, the subject was further complicated by a remark of Wachsmuth and Springer in a note to page 77 to the effect that the Belgian species on which De Koninck and Le Hon founded the genus belongs to *Onychocrinus.* Bather in Lankester's Zoology, 1900, does not recognize *Forbesiocrinus* as a genus, but on page 190 mentions "*Forbesiocrinus agassizi*" which he says may be placed in the family Sagenocrinidae; adding that "patelloid plates are richly developed, but are absent from *Sagenocrinus.* Otherwise the two genera agree closely." This course was in harmony with my own opinion then held, as already stated under the genus *Sagenocrinus,* and in 1901 (*Uintacrinus,* Mem. Mus. Comp. Zoology, vol. 25, p. 71) I stated my belief that "the name "*Forbesiocrinus*" will have to be given up, as suggested by Bather. The English species taken by De Koninck as type is a *Taxocrinus* pure and simple, while the two specimens figured by him from Belgium surely belong to the type for which the genus *Onychocrinus* has been established." Subsequent investigation, with the aid of the new material above mentioned, led me to reconsider this opinion both as to the validity of the genus *Forbesiocrinus* and the reference to *Onychocrinus,* which was a reiteration of the expression of 1897 above cited founded upon a misconception of the specimen now figured on Plate XXIII, figure 1*a,* as already explained. This resulted in the conclusion stated by me in 1902 (Amer. Geologist, vol. 30, p. 90) which will be here restated:

Bearing in mind Wachsmuth and Springer's description of the anal side of *Taxocrinus,* and remembering that this is the main character upon which the entire family Taxocrinidae is founded under my classification, let us now return to the original description by De Koninck and Le Hon of their genus *Forbesiocrinus.* In addition to the generic formula, they gave not only an elaborate description in the terminology of De Koninck and Le Hon, but a generic diagram (which I have copied on Plate XXII), together with figures and description of two specimens. From these it clearly appears that the posterior basal, instead of being truncate and followed by a tube-like series of plates bordered by fragile perisome, is angular above, supporting two anal plates suturally joined to the adjacent brachials and followed by some others. Although they did not dwell upon this character in their discussion of resemblances and differences, nevertheless the structure as above stated clearly appears in the generic diagram; and in the diagnosis of "caractères génériques" it is given as follows: "Ce qui distingue surtout le côté anal des autres, c'est que l'extrémité supérieure de la pièce basale qui y correspond est soudeé à deux petites pièces anales et qu'elle porte, par conséquent, deux facettes articulaires de plus que les quatre autres pièces basales, dont aucune ne se soude directement aux pièces interradiales" (*op. cit.*, p. 119).

It is evident from these facts that the genus as proposed by De Koninck and Le Hon is perfectly distinguished from *Taxocrinus,* and that upon structural grounds alone its validity should be no longer open to question. I have, however, made the above somewhat full extract from their description in order to emphasize the further fact that the structure described and illustrated is totally different from that of Phillips's species *Taxocrinus nobilis,* under which name they erroneously identified the specimens upon which their generic diagnosis was founded. Considering only Phillips's figure in the Geology of Yorkshire, plate 3, figure 40, with its one to three small "interradial" plates, and no trace of the interaxillaries which led the authors to believe the calyx in their genus extended to the last arm bifurcation; and bearing in mind that it represented a large and mature specimen in which interbrachial structures, if present, would be at their fullest development;—it must have been held, even with the views expressed by De Koninck and Le Hon themselves, to be a very different species; and it is difficult to understand how so ardent a student of the crinoids as De Koninck could ever have confounded the Belgian specimens with it.

When in addition to this we examine the type specimen in the Gilbertson collection in the British Museum, which I have refigured after additional cleaning (Pl. LIV, figs. 1*a*-*c*), showing the truncate posterior basal with the clear trace of a facet for the support of a vertical series of anal plates, it must become sufficiently apparent that the identity of De Koninck and Le Hon's genus with the species *Taxocrinus nobilis* is absolutely negatived by their own description and diagram. And if to these facts we add the further evidence afforded by my new figure of one of the types showing the actual construction of the anal side in the original specimen, and in my own better preserved specimens, the above conclusion becomes irresistible. As if to make assurance doubly sure, I received from M. Piret after the foregoing paragraph was written an additional piece of confirmatory evidence in the shape of a good specimen of an unquestionable *Taxocrinus* from the same beds at Tournai, the first one ever found (Pl. LIV, figs. 2*a*, *b*). It shows that the two genera existed side by side in the Tournai limestone; and if De Koninck had had this specimen in hand he would never have confused his others with Phillips's species.

We may therefore take this fact as proved, viz., that the Belgian type upon which De Koninck and Le Hon founded their genus is not identical with the English species of Phillips to which they referred it; or, in other words, that *Forbesiocrinus nobilis* De Koninck and Le Hon and *Taxocrinus nobilis* Phillips are two entirely different species.

With this proposition established, we are in a position to consider the question of the validity of the name *Forbesiocrinus.* As to this two courses are open, for each of which good arguments can be given:

1. De Koninck and Le Hon established the genus on Phillips's *Taxocrinus nobilis* as the type and only species. This has the characters of *Taxocrinus* and must remain in that

genus. Therefore *Forbesiocrinus* is without a type species—its type belonging to a prior genus; it becomes a synonym of that genus and must be abandoned. Or—

2. True, the authors believed their type species to be the same as Phillips's species, listed it as such in the synonomy, and noted its occurrence as from both English and Belgian localities. In this they were mistaken. But they described their species under the name *Forbesiocrinus nobilis,* from original material, with good figures, and also gave a clear generic description and diagram founded wholly upon their own specimens and not in any wise upon the characters of the English species, which although erroneously identified by them, is in fact totally different. Hence the error of the authors was not in their definition, but in their synonymy; and notwithstanding De Koninck and Le Hon's statement the type species is not, and never could have been, *Taxocrinus nobilis* Phillips, but is *Forbesiocrinus nobilis* De Koninck and Le Hon;—a name attached to a definite form, with adequate description and figures. Thus we have a genus duly published, with a diagnosis, a generic diagram, and a described and figured species under it; therefore the name is valid, and stands for the type and species which the authors actually figured and described, regardless of what they called it in their synonymy.

In these circumstances to hold the name invalid, so as to warrant the proposal of a new one in place of it, would in my opinion be invoking a very narrow and doubtful technicality for an unnecessary and insufficient purpose; whereas to maintain the name will not only leave the credit where it belongs and avoid much needless confusion, but will be consistent with the spirit of the International Code, and in my opinion in no wise countervailed by its letter. This was the view I adopted in 1902, and further consideration has shown me no reason to change it.

The earliest known occurrence of this genus, as before stated, is in the Mountain limestone of Belgium, and in the approximately equivalent Waverly—Choteau—Knobstone of the United States. The *F. wortheni* type begins in the upper division of the Burlington limestone; and although crinoids in the lower division are very abundant, finely preserved and of great variety, not a specimen belonging to this type has been found from it among all the great collections made at the typical locality during the past 50 years. This type reached its culmination in the Keokuk limestone, both in abundance and variety, and ended in the Warsaw; it is found in fine preservation at many localities in Iowa, Illinois, Missouri, Indiana, Kentucky, and Tennessee. The specimens in the Warsaw are usually large, and of striking appearance. Some of the species described are exceedingly well marked, while others are poorly defined, and some undoubtedly synonyms. The genus has never been recognized in either the St. Louis or Kaskaskia, although in the literature several species of it will be found recorded from those formations. It is one of the most conspicuous forms of all the Carboniferous Flexibilia, being rivaled only by *Onychocrinus* of the Taxocrinidae.

The specimen described by McChesney as *Forbesiocrinus pratteni* is not from the Carboniferous of Alabama as stated in the description, but from the Helderbergian of western Tennessee, and is a Camerate crinoid, *Scyphocrinus.*

The types represented by *F. nobilis* and the later species like *F. wortheni* fall into two rather sharply differentiated sections, which might upon some grounds be placed in different genera. But as in other strong Carboniferous genera, like *Taxocrinus* and *Onychocrinus,* it has been found best to admit a wide range of variation in the interbrachial structures rather than to subdivide them upon too fine distinctions, I think it preferable to do so in this case, especially as we thus avoid changing the generic name of a large number of species, including those by which the genus is best known.

The number of described species remaining under this genus is rather large; some are clearly synonyms, and in many of those retained the characters are not easy to define, being mainly founded upon slight variations in form and proportions which shade into one another. Ten species are recognized, which may be arranged as follows:

### The Species of Forbesiocrinus

- I. Solid anal and iBr plates confined to lower part of areas.
  - iBr areas narrow. iBr few.
    - Surface smooth. Specimens small .................... *F. communis.*
  - iBr areas wide. iBr well-developed. Surface pustulose.
    - Specimens large .................... *F. nobilis.*
- II. Anal and iBr areas filled with solid plates connecting with tegmen.
  - Calyx plates elevated.
    - Rays prominently elevated.
      - Calyx obtusely pentagonal.
        - R and lower Br long.
          - Calyx plates nodose.
            - Specimens large. IBr 2 .................... *F. agassizi.*
            - Specimens small. IBr 3 .................... *F. burlingtonensis.*
    - Rays but slightly convex.
      - Calyx obtusely decagonal, subglobose.
        - R and lower Br short and wide.
          - Calyx plates slightly rounded.
            - Arms long, flat, abutting.
              - Calyx short .................... *F. wortheni.*
            - Arms rounded, separated.
              - Calyx higher .................... *F. multibrachiatus.*
          - Calyx plates tumid.
            - Arms flat, delicate, abutting.
              - Calyx higher .................... *F. washingtonensis.*
      - Calyx circular, conical.
            - Arms rounded, well separated .................... *F. pyriformis.*
          - Calyx plates flush with general curvature.
            - Calyx globose, circular .................... *F. greenei.*
      - Calyx lobed, pentagonal.
            - IIBr$_3$ prominently convex .................... *F. saffordi.*

### **Forbesiocrinus communis** Hall

*Plate XX, figs. 4-8*

*Forbesiocrinus communis* Hall, Prelim. Notice 17th Rep. N. Y. St. Cab. Nat. Hist., 1863, p. 6 (Final Rep., 1864, p. 55).—Hall and Whitfield, Geol. Surv. Ohio, Pal. II, 1875, p. 169, pl. 12, figs. 4, 5 (not fig. 3).
*Taxocrinus communis*, Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1865, p. 140.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 48.

A rather small species. Crown spreading to top of first IIBr, where height to width is 1 to 1.5. Spread of calyx from base, 1 to 5.5; rays and their divisions deeply rounded, with wide spaces between them. Surface smooth; sutures more or less sinuous, not beveled or imbricated. Maximum crown to fourth bifurcation, 32 mm. high by 22 mm. wide; base, 4 mm.

IBB low pentagons as seen beyond the column. BB not over half the size of RR, except post. B which is larger than the others, angular above, supporting 2 (sometimes 3) rather small plates suturally united to adjacent Br; these are followed at the right side by a series of small plates united to r. post. ray which may extend as high as the second bifurcation. Primary iBr one large plate, with a small one in second axil; the remainder of the areas above this and those in anal interradius followed by perisome. IBr 3; IIBr 4 or 5, with two or more bifurcations beyond; rays strong at first, diminishing rapidly at each bifurcation, and the divisions widely separated. Column expanding above, with very thin ossicles which become longer and alternating after about the first twenty. Limits and characters of tegmen unknown.

Hall described under *Forbesiocrinus communis* two widely distinct species, his figure 3 being a *Taxocrinus,* while figures 4 and 5 fall under the above description. The specimens occurred in a layer of bluish grey, argillaceous limestone in the lowest part of the Cuyahoga shale at the base of the Lower Carboniferous. They were associated with a fauna which, independent of the crinoids, was declared by the late Professor C. L. Herrick (who made a special study of the Cuyahoga formation in connection with the Ohio Geological Survey) to bear an "unmistakable resemblance to the so-called Sub-Carboniferous of Belgium, especially to that of Étage 1, the Limestone of Fornai [Tournai]" (Bull. Geol. Soc. America, vol. 2, 1890, p. 39). The locality produced a considerable variety of crinoids, and the specimens were well preserved, as may be seen by reference to those figured on plates 11 and 12, vol. 2, of the Paleontology of Ohio. They were evidently deposited in a fine, calcareous mud, upon a quiet sea bottom; the calyx plates were but little disturbed and usually the arms and stems were attached, although few in that state were secured by the collectors. This matrix is rather firm and homogeneous, favorable to the preservation of the finer parts, but its color is so near that of the fossils themselves that it is impossible to clean them so as to show such delicate structures as the finely plated perisome; but everything in the way of solid plates can be uncovered with precision.

The five specimens of this species figured herein have been cleaned with the utmost care, with a view to ascertaining the exact nature of the structures between the rays. One effect of this may be seen by comparing my figure 5*b* on Plate XX with Hall's figure of the same specimen on plate 12 of the Ohio Report, in which the anal structures above the posterior basal are not shown at all, not having been exposed on the specimen until now. I mention these details to support the statement that in my opinion the plates of the interbrachial and anal areas shown by the figures are substantially all the solid plates existing in this form between the rays, although I have not been able to actually identify the perisome connecting with them. The series of plates following the first range of anal plates along the left margin of the posterior ray are suturally united to it certainly to the height of the first secundibrach (Pl. XX, figs. 5*b,* 6, 7). The left margin of this series is rounded without the slightest indication of any angular or sutural face, but on the contrary it is just such an edge as we find along the distal face of interbrachials in *Onychocrinus* and *Taxocrinus,* and at the margins of the rays in *Temnocrinus,* where we know that perisome was attached. The same thing is true of the other ray margins, which are all rounded with no sign of sutural attachment above the interbrachial plate. These facts lead to the conclusion that the remainder of the anal area was not filled by solid plates, but by perisome adjoining the margin of the series of plates which we see in figures 5*b* and 6.

The superficial resemblance of this species to *Temnocrinus* is quite strong. A slight upward extension of the anal series of the latter, and the interpolation of an infer-radial in the four regular rays, will produce this form in all essential characters. It is well distinguished from the Belgian species by its single interbrachial and greater extension of the dextral anal series, as well as by its smooth surface.

*Types.* Hall's originals (Pl. XX, figs. 4, 5) are in the New York State Museum at Albany. The other specimens figured are in the author's collection.

*Horizon and locality.* Base of Lower Carboniferous, Cuyahoga shale; Richfield, Ohio.

The fact that in a prominent text-book of paleontology a widely different horizon is given for this and several other species renders it advisable to append a more detailed statement as to the geological position of the Richfield, Ohio, crinoids. The protracted controversies relative to the Waverly Group of Ohio have given rise to some curious differences of opinion as to the actual horizon of the crinoids from Richfield, Summit County, in northern Ohio, described by Hall in the 17th Report of the New York State Cabinet of Natural History, 1886, and afterward in volume 2 of the Paleontology of Ohio. At the time these descriptions appeared, it was taken for granted that the specimens were derived from a horizon approximating in a general way the Kinderhook of the Mississippi River region—a formation which was considered by Hall, White, and the earlier geologists to be late Devonian, equivalent to the Chemung of New York. Later, Meek and Worthen demonstrated to the satisfaction of geologists generally the Carboniferous facies of this formation—a conclusion which was afterward strongly confirmed by Professor Calvin[1] in connection with his discovery of an undoubted Devonian (probably Chemung) equivalent at Lime Creek, Iowa, underlying the Kinderhook beds.

The peculiar character of the crinoid fauna at Richfield was quite consistent with such a geological position, and no one familiar with the stratigraphic range and distribution of the crinoids saw any reason to doubt the correctness of the original interpretation. Hall himself in his preliminary notice (17th Report, p. 51), after reviewing the evidence afforded by the entire collection, said: " I should infer that the geological position of these species is between the Hamilton Group and the Lower Carboniferous beds." When it was found, however, that the term " Waverly " had been extended in Ohio to include a number of beds in central and southern Ohio which were undoubted equivalents of the Burlington and Keokuk of Ohio and Illinois, there was a disposition in some quarters to refer the Richfield crinoidal beds, which are in part of a bluish grey color, to the Keokuk Group. This was done by Cooper in 1888 (Bull. Laboratory of Denison University, vol. 4, p. 123), who located them in the upper, or Keokuk, subdivision of the Logan division of the Waverly.

In 1891 Professor C. L. Herrick (Bull. Geol. Soc. America, vol. 2, pp. 31-48), as the result of an extended and special field investigation, made a determination of the question which ought to be conclusive. He showed that the crinoids from Richfield are derived from a horizon of slow and uninterrupted transition from Devonian to Carboniferous—a period of almost continuous sedimentation, wherein the disturbances " were neither violent nor extensive enough to seriously interfere with the peaceful evolution of types " (p. 32); that they occur in the Cuyahoga shales (p. 42); that he can " positively assert that the Cuyahoga shale as represented in the northern tier of counties (Summit, etc.) is identical with that part of the Waverly lying below Conglomerate I—*i. e.,* below the undoubted actual equivalent of the Kinderhook of central Ohio " (p. 37). And he adds on p. 36: " The work of the present season has happily set the general question quite at rest, and will doubtless shed a flood of light on the affinities of the crinoids of the Cuyahoga which have caused so much discussion. Their curious resemblances to the Devonian species and the strange commingling of Carboniferous characters can no longer be regarded as abnormal."

Notwithstanding the evidence furnished by these investigations, and contrary to the most palpable faunistic indications of the fossils themselves, S. A. Miller in the Second Appendix to his North American Geology and Palaeontology, 1887, referred every one of these Richfield crinoid species to the Keokuk Group; and afterwards in Bulletin 12 of the Illinois State Museum, p. 11, it was stated by Miller and Gurley that the rocks of the Richfield crinoids " are now known to belong to the Keokuk." This involves the position of four species of the Flexibilia. Of these *" Forbesiocrinus " lobatus* var. *tardus* is a clear survival of a Devonian type, *Dactylocrinus,* while *" F." communis,* in part, represents the most primitive type of *Forbesiocrinus,* in no way comparable to the mature forms of that genus found in the Keokuk. Among Camerata, Hall's *"Actinocrinus" viminalis* is an *Amphoracrinus*, and his *"A." daphne* is a *Cactocrinus*—two genera which do not pass beyond the Lower Burlington, and the latter of which is found in the Kinderhook of Iowa. *"A." helice* is an *Aorocrinus,* a genus which begins in the Devonian and ends in the Upper Burlington. Not a single species, or type, of the entire crinoidal fauna resembles in the slightest degree those characteristic of the Keokuk. In 1902, in a letter to me discussing the subject, Professor Herrick wrote: "You may quote me as verifying the Kinderhook age of the lower beds at Richfield upon ample palaeontological evidence."

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[1] American Jour. Sci., June, 1883, p. 432.

### Forbesiocrinus sp.

*Plates XXIII, figs. 11-13; XXIV, figs. 28, 29*

I have figured some fragmentary specimens from the Knobstone formation of Indiana and Kentucky which while not sufficient for specific definition prove the presence of the genus in those rocks. The fossils occur in thin bands of shale and limestone; they are for the most part much flattened, usually crushed so that on weathering they become disintegrated and are found as scattered plates among the debris. The most careful search made by three different collectors has thus far failed to locate the crinoids in place so that they could be obtained in better condition by quarrying. These fragments were associated with *Wachsmuthicrinus, Mespilocrinus* (both mainly Lower Burlington genera), and a large assemblage of Inadunate and blastoid species of distinctly Lower Burlington and earlier types.

The most important of these fragments is the reconstructed ray, Pl. XXIII, figures 11*a, b.* It contains only the first four primary plates, and these not from the same individual; but the succession of interlocking angular faces for two ranges of interbrachials with sutures of deep ligament fossae up to the middle of $IBr_2$, followed by a corrugated margin on the remainder of that plate and the axillary primibrach, shows beyond any doubt a structure identical with that of the type species. There is nothing else with which it might be confounded. The relative thickness of the plates, 0.3 to 1 in width for the radial, is decisive against their belonging to any *Taxocrinus.* The surface ornament is almost identical with that of *F. nobilis,* and appreciably different from that of certain fragments from the same locality which, on account of the greater thickness of the plates, I have referred to *Taxocrinus* (Pl. LIV, figs. 19*a, b, c,* 20). There was evidently a considerable variety of Flexibilia in these beds, and if we had the specimens entire they would doubtless add much to our knowledge of these forms.

I also figure (Pl. XXIV, figs. 28, 29) two plates belonging to forms of this genus from equivalent strata at Lake Valley, New Mexico; and another (Pl. XXIII, fig. 9) from Fern Glen, Missouri.

### **Forbesiocrinus nobilis** De Koninck and Le Hon

*Plates XXI, fig. 1; XXII, figs. 1-4; XXIII, figs. 1-8, 10; XXIV, figs. 1-27*

*Plante polypiere,* Witry, Mem. Acad. Imp. et Roy. Bruxelles, 1780, T. 3$^{me}$, p. 18, pl. 3, fig. 3.

*Forbesiocrinus nobilis* De Koninck and Le Hon, Recherch. Crin. Carb. Belgique, 1854, p. 121, pl. 2, figs. *2a, b.*—Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1865, p. 139; Geol. Surv. Illinois, II, 1866, p. 271.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 52; N. A. Crinoidea Camerata, 1897, p. 77, pl. 8, figs. *6a-c.*—Springer (*Taxocrinus nobilis*), Amer. Geologist, XXX, 1902, p. 90.

Type of the genus.

Specimens of large size. Crown elongate, rapidly spreading; with rays folded widest at top of IAx, where height to width is about 1 to 1.6; spread from base, 1 to 3.5; cross-section quinquelobate. Rays and arms stout and deeply rounded; interbrachial areas wide and depressed above iBr. Surface finely pustulose. Crown of mature specimen, 90 mm. high by 45 mm. wide when folded; would be much wider if rays expanded; base, 13 mm.

IBB low, slightly visible above column, resembling a thickened proximal columnal. BB large, upper angle acute, sometimes tongue-like with curving sides; post. B much the largest, angular, supporting two good-sized plates, with a few smaller ones above probably extending into a tube. iBr not extending higher than the axillary IBr, usually limited to about 4 to 9 plates, one large with one or more ranges of smaller ones succeeding; iIIBr usually present. RR larger than BB. IBr 3, increasing in width beyond iBr; IIBr 4; IIIBr 6 to 8, with three or more bifurcations beyond; higher brachials becoming short and deep. Column large, expanding next to calyx, where the columnals are very thin, 2 to the mm. for a distance of about 30 mm.; below this alternating with somewhat longer ossicles. Integument above iBr not preserved, and tegmen unknown.

The literature and morphological details of the species have been discussed under the genus. In the figures of De Koninck and Le Hon the surface ornament appears somewhat coarser and sharper than it is upon the original of their figure *2b,* or upon my better preserved specimens.

*Types.* The original of De Koninck and Le Hon's figure *2b* (Pl. XXII, figs. *1a, b*) is in the Musée Royale d'Histoire Naturelle, Brussels; that of their figure *2a* in the Muséum d'Histoire Naturelle, Paris. The other specimens figured are in the author's collection, and were collected during a series of years by M. Ad. Piret, of Tournai.

*Horizon and locality.* Lower Carboniferous, Étage 1, Tournai limestone; Tournai, Belgium.

### **Forbesiocrinus agassizi** Hall

*Plates XXI, fig. 2; XXV, figs. 1-6; XXVI, figs. 1-2*

*Forbesiocrinus agassizi* Hall, Geol. Surv. Iowa, I, pt. 2, 1858, p. 631, text-fig. 103; Supp. Geol. Iowa, 1860, p. 65; Bull. I, N. Y. St. Mus. Nat. Hist., Photo. Plates, 1872, pl. 7, figs. 1, 2.—Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1865, p. 140.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, pp. 45, 52; N. A. Crinoidea Camerata, 1897, p. 77.—Keyes, Geol. Surv. Missouri, IV, 1894, p. 224, pl. 30, fig. 3.—Bather, Rep. British Assoc. for 1898 [1899], p. 923; Treatise on Zoology (Lankester), pt. 3, 1900, p. 190.—Springer, Amer. Geologist, XXX, 1902, p. 89; Jour. Geology, XIV, 1906, p. 489.

*Forbesiocrinus Agassizi* var. *giganteus* Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1861 (1862), p. 131; Geol. Surv. Illinois, III, 1868, p. 495, pl. 18, fig. 3.

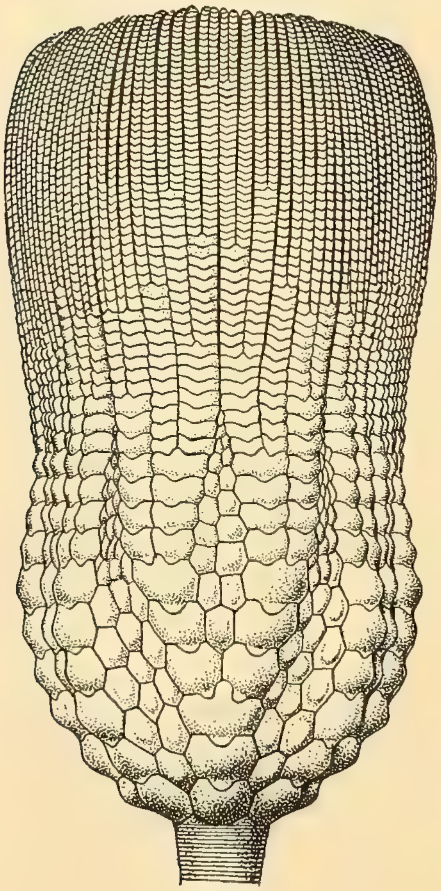

Fig. 35
*Forbesiocrinus agassizi*

A very large species. Crown elongate, with long arms. Rays strongly convex and prominent; iBr areas depressed. Calyx moderately spreading from the column to greatest width at about IIBr$_3$, where average height to width is about 1 to 1.6; height to width of calyx at upper limit of iBr, 1 to 1; height to width of crown, 1 to 0.67; height of calyx to crown, 1 to 1.6; spread of calyx from column facet, 1 to 5. Cross-section at IIBr$_3$ obtusely pentagonal; side outline curved. Surface smooth or finely granulose. All calyx plates nodose or abruptly elevated in the middle, while flat toward the margin; those of iBr round, and of Br transversely elongate. Brachial sutures deeply sinuous, with patelloid processes large. Base flush with column facet. Dimensions in millimeters of a very mature specimen with arms folded at about the fourth bifurcation, and of the smallest of fourteen specimens, similarly folded, are as follows: Large specimen; height of crown, 10 mm.; of calyx to top of iIIBr, 65; width of calyx, 62; of base, 18; column below taper, 12. Small specimen; height of crown, 65; of calyx, 50; width of calyx, 50; of base, 12; column below taper, 8. Arms of a large specimen outstretched to near the end, 85 mm.

IBB flat like a columnal, without visible angles and scarcely distinguishable. Regular BB small, appearing as low pentagons, or as triangles; post. B about as high as RR, angular above, with right shoulder the longest; it is followed by two large anal plates, and these by others in ranges of 3, 4 and 5 abreast, gradually diminishing and passing into the tegmen at about the upper IIIBr. First iBr about the size of first anals, followed by similar plates to the same height as in the anal area, and about one plate less in width at corresponding levels; iIIBr areas similar and proportionally smaller. RR and IBr three or four times as large as BB, and fairly uniform in width. Height of B to R to IAx, 1:2.5:2.7.

IBr 2; IIBr usually 3, exceptionally 4. All brachials below IVBr more than half as high as wide. In a large specimen the height and width of the successive plates are as follows: B, 3.5 x 9; R, 10.5 x 12; IBr$_1$, 9 x 12; IBr$_2$, 10 x 14; IIBr, 8 x 10; IIIBr, 5 x 8; IVBr, 2 x 6; VBr, 2 x 6.5; VIBr, 1.5 x 4; VIIBr, 1.2 x 1.5; thus while the lower and more distal brachials are nearly as high as wide, the intermediate ones, about where the free arms commence, are relatively much lower and wider. In another equally large specimen where the full connection cannot be traced, there are arms toward the distal end with brachials about 1 mm. high and wide, and 2 mm. deep. The number of brachials of the successive orders in the ray follows a fairly definite rule for the two branches of the dichotoms, viz.: IIBr usually 3; then 4 or 5 and 7 or 8 IIIBr, the larger number at the outer side of the dichotom; 5 to 8 and 10 to 15 IVBr, with the smaller number at the outside; 8 to 12 and 15 to 20 VBr, the smaller number still at the outside. There are two or more bifurcations beyond this, with arms tapering very gradually and becoming very deep. Column large, tapering from the calyx; proximal columnal the same diameter as the infrabasal ring, which is scarcely distinguishable from it, and usually, but not always, adhering when the stem is displaced; upper columnals extremely thin, numbering 25 in the first 10 mm. diameter in about that distance, beyond which the column becomes cylindrical; there a slight alternation of thicker and thinner columnals begins, gradually becoming more pronounced downward; but at no place are the ossicles very thick, and all are smooth and of even diameter. When weathered they show strong crenulation at the ends of the radiating striae of the joint faces.

This species has always been esteemed by collectors the finest fossil in the Burlington limestone, and with the possible exception of *F. saffordi* it is the largest crinoid known among the Flexibilia. It is one of the rarer species, not over twenty-five specimens having been found among all the collections, of which more than half are in the author's material. It is usually found with the arms inrolled from the fourth to the fifth bifurcation, and in none of the specimens are they extended to their full length, though probably nearly so in figure *1a*, Plate XXVI. The calyx may be considered to extend to about the third bifurcation, where the interbrachials pass into the tegmen, and the arms as shown by that specimen are at least once and a half as long. The brachial series are strongly and abruptly elevated above the level of the interbrachial areas, and look like rough longitudinal ribs. This, with the strongly convex, often nodose, plates, both brachial and interbrachial, and the unusual length of the lower brachials, gives to this crinoid a very striking appearance by which it is easily recognizable from imperfect fragments. There is a tendency to contraction at the upper limits of the interbrachials where the arms become free. All the specimens are more or less flattened, but the natural contour and proportions are correctly shown in the restoration (text-fig. 35), made from careful measurements on several specimens of about the same size

The mode of union of calyx plates in this species is well shown by the figures from some dissected parts of specimens. At the brachio-interbrachial and other non-articulating sutures the fossae, though large, are interrupted by numerous small contact areas (Pl. XXV, figs. 3*c*, 5*c*), so that the ligamentous masses were not so large as in *F. nobilis.* The articulating sutures have fairly well-defined paired muscle-fossae, except upon the radial which seems unpaired here as in other species (Pl. XXV, figs. 6*a*, 5*e*).

In no species is the so-called "patelloid" structure at the brachial sutures carried to a greater extreme than in this and its Burlington associate, and it was here that attention was first directed to this character by Hall, as heretofore explained. In some specimens, especially of the latter form, it affects the shape of the entire plate, the sinuosity beginning at the margins and extending in a deep, broad curve to the middle, and the transverse elevation of the plates being curved to correspond with it (Pl. XXVI, figs. 4, 5).

The taper at the proximal end of the column is not so pronounced in this species as in some others; it all occurs within a short distance, and is sometimes not very marked. This was the case with Meek and Worthen's variety *giganteus,* which they describe as showing a perfectly straight column, whereas their figure shows that it diminishes from 13 mm. to 10 in a short distance. The orientation of the axial canal is somewhat irregular, being clearly interradial in some specimens, while in others it is rather indefinite.

The most peculiar thing about this species, in which it differs from all others of the genus, is that it has only two primibrachs. This is no sporadic variation. It is constant in every ray of every well-preserved and normal specimen known to me. Hall, in the explanation of his figures of the types on plate 7 of Bulletin 1 of the New York State Museum, distributed by him in 1872, speaks of some irregularity in these plates, as varying from two to four—meaning all the primary plates including the radial and the first axillary. Those with the latter number I have separated specifically for reasons which will follow. Those with the former may be abnormal in one or more rays, although I have not seen any such among my specimens, while I have some crushed in such a way as to give the impression of only one primary plate in a ray above the radial, which was always corrected by closer inspection or further cleaning. I have before me 14 specimens in which 55 rays are visible to the first axillary, and there is among them not a single exception to the number of two primibrachs. Meek and Worthen's variety *giganteus* is clearly abnormal in the ray from which the figure was drawn, and there are fractures about the base which were not correctly interpreted by the artist. Neither is there any exception among the specimens which I have separated on account of having three primibrachs, save in one young individual.

It would seem, therefore, that this genus, evolving from a Silurian form like *Sagenocrinus* or *Temnocrinus,* underwent its final transformation in the Burlington limestone by taking on an additional primary plate in each ray; and that this was accomplished by a specific change far more complete and decisive than we find in some other cases where the modification was going on in the Devonian. Doubtless if we had all the stages of this development through the Devonian we should see phases of individual variation; but the final stage became firmly established in the genus, with one species tenaciously holding on to its Silurian type of ray structure. It is singular that with this apparently straight line of derivation, no trace of this type has been found in the prolific crinoidal deposits of the Lower Burlington beds at the same locality. We must remember, however, in this and all similar cases what we are constantly prone to overlook—that our collections, even from these prolific and well searched formations, represent only a mere atom of what actually existed during their epoch, or was deposited in their sediments.

*Types.* Hall's original is in the University of Chicago; the other specimens figured are in my own collection. The original of figure 2, Plate XXV, one of the finest specimens known, was found by Mr. J. O. Beebe, a most zealous and intelligent Burlington collector, who presented it to me for use in this work.

*Horizon and locality.* Lower Carboniferous, Upper Burlington limestone; Burlington, Iowa; Henderson County, Illinois; and Washington County, Indiana.

### **Forbesiocrinus burlingtonensis** n. sp.

*Plate XXVI, figs. 3-5*

I have separated under this name those specimens occurring in the Burlington rocks which have three primibrachs. The description of *F. agassizi* will apply to them in other respects save two; (1) the extreme sinuosity of the brachial sutures which exists in all well-marked specimens; and (2) the size of the specimens. The largest of the present form is smaller than the smallest of the other. Five representative specimens of *F. agassizi,* including the largest and the smallest, compared with five similar specimens of the present species, give the following average dimensions:

*F. agassizi:* Height of crown, 96 mm.; of calyx, 57; width, 65; base, 13.

*F. burlingtonensis:* Height of crown, 59 mm.; of calyx, 29; width, 33; base, 9.

I have eight specimens of this species, in the largest of which the crown is 65 mm. high; calyx, 30; width, 43; base, 11; column at 20 mm. below, 8. In these eight specimens 26 rays are visible, and every one of them has three primibrachs. A single small specimen not included in the above averages, only 27 mm. high, has in four visible rays 3 with 2 IBr, and 1 with 3. This is the only case of individual irregularity I have found in either form. Size alone, among specimens of the same locality, is ordinarily no criterion of a species; but in this case its correlation to such a degree of constancy with the number of primibrachs and another character must be of more than ordinary significance. For these reasons I feel warranted in separating these two forms, which are in fact far more easy to distinguish than some of the Keokuk species heretofore described by others. There may be noted in addition the tendency in this species to form a vertical row of anal plates, as shown on Plate XXVI, figure 5 (the appearance of bifurcation on two plates in this figure is erroneous), which occurs not unfrequently in some of the Keokuk species, but which I have not observed in *F. agassizi.*

*Types.* Author's collection, except figure 4 which is in the Museum of Comparative Zoology at Harvard College.

*Horizon and locality.* Upper Burlington limestone; Burlington, Iowa.

### **Forbesiocrinus wortheni** Hall

*Plate XXVII, figs. 1-8*

*Forbesiocrinus wortheni* Hall, Geology Iowa, I, pt. 2, 1858, p. 632, pl. 17, fig. 5; Supplement Geology Iowa, 1859 (1860), pl. 3, fig. 7.—Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1865, p. 140.—Meek, Amer. Jour. Sci., ser. 3, VII, 1874, p. 191.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 52.—Whitfield, Bull. Amer. Mus. Nat. Hist., 1882, p. 96.—Keyes, Geol. Surv. Missouri, 1894, p. 224.

*Forbesiocrinus jerseyensis* Miller and Gurley, Bull. 8, Illinois St. Mus. Nat. Hist., 1896, p. 58, pl. 4, figs. 2, 3.

*Forbesiocrinus macadamsi* Miller and Gurley, Bull. 9, Illinois St. Mus. Nat. Hist., 1896, pl. 5, figs. 1, 2.

Not *Forbesiocrinus wortheni,* Meek and Worthen, Geol. Surv. Illinois, V, 1873, p. 496, pl. 14, fig. 2, pl. 15, fig. 7.

A large species. Crown elongate with long arms. Rays moderately rounded, in rather close contact above iBr; iBr areas slightly depressed. Calyx moderately spreading to about $IIBr_3$, where average height to width is 1 to 2;

height of calyx to width, 1 to 1.5; height of calyx to crown, 1 to 2; spread of calyx from base, 1 to 3.2; height to width of crown, 1 to 0.7. Cross-section obtusely decagonal, side outline curved. Base flush with column facet. Surface smooth. Calyx plates flat or gently rounded, without median elevation. Sutures sinuous, patelloid processes not prominent except in the arms. Height of crown of large specimen, 65 mm.; of calyx 36; width 52; of base 13; of column at lower end of expansion, 9 mm. Average of these dimensions in five specimens, 50; 25; 37; 11.4; 8.

General arrangement of plates as in *F. agassizi,* but iBr less numerous, RR and lower Br plates much shorter. Primibrachs 3. Height of B to R to IBr, 1:1:1.25. Height and width of successive plates in a large specimen: B, 4 x 7; R, 4 x 9; IBr, 4 x 9; IIBr$_2$, 3 x 8; IIIBr, 2.2 x 5; IVBr, 2 x 4. IIBr, 3 or 4; numbers of successive orders of brachials as in *agassizi.* Above the third bifurcation the outer ramus of each dichotom is much wider than the inner; arms infolding at about fifth to sixth bifurcation, with probably more beyond. Rays low convex, arms flat, usually abutting above iBr, though in smaller specimens sometimes more rounded and slightly separated. The calyx is relatively lower than in *F. agassizi,* and in the average of the specimens the crown more slender and arms as usually exposed longer; the base and column relatively broader. The column continues strong and cylindrical below the taper, with simple alternation of thicker and thinner non-projecting ossicles, becoming more nearly equal downward; it is preserved in one specimen to a length of 17 cm. with no sign of cirri or roots, or change in diameter.

This is the species of the western or typical Keokuk limestone beds along the Mississippi River, being found at Keokuk, and various localities in Iowa, Illinois and Missouri, from above Nauvoo to the mouth of the Illinois River in Jersey County. It is readily distinguished from its Burlington predecessors by the lack of nodose elevation of the plates, and its shorter lower brachials; but not so easily from *F. multibrachiatus* of the eastern Keokuk. Hall's type is vertically crushed, and his figure did not disclose the base, owing to injury and partly to adhering matrix; this has been removed, and the new figure (Pl. XXVII, fig. 1) shows all the essential characters very well for comparison with the more perfect material now available. This consists of a series of excellent specimens from Nauvoo, Niota, Keokuk, and Jersey County, Illinois. The fine specimen pictured in figure 3 was found by the late Lisbon A. Cox, the veteran collector of Keokuk, to whose industry in that field during 30 years we are indebted for by far the greatest collection of Keokuk crinoids ever brought together. All the specimens are much flattened, and the true contours of the crown are not shown by the figures.

The specimen figured under this name by Meek and Worthen, in volume 5, Geol. Surv. Illinois, plate 14, figure 2, is from the eastern Keokuk of Indiana at the typical locality of *F. multibrachiatus,* and must be referred to that species. *Forbesiocrinus macadamsi* of Miller and Gurley, from Jersey County, Illinois, is a fine and characteristic example of the present species; but their figure of it, Bulletin 9, Illinois State Museum, plate 5, figure 1, is wholly incorrect as to the basal plates. Their *F. jerseyensis,* from the same locality, is also a synonym.

*Types.* Hall's original is in the Worthen collection now in the University of Illinois; that of figure 8 in the University of Chicago; the others figured are in the author's collection.

*Horizon and locality.* Lower Carboniferous, Keokuk limestone beds west of the Illinois Coal Measures; Keokuk, Iowa, and various localities along the Mississippi River from Nauvoo to the mouth of the Illinois River, associated with *Agaricocrinus wortheni, Dorycrinus mississippiensis,* and *Uperocrinus nashvillae.*

### **Forbesiocrinus multibrachiatus** Lyon and Casseday

*Plates XXVIII, figs. 1-19; XXIX, figs. 4, 5*

*Forbesiocrinus multibrachiatus* Lyon and Casseday, Amer. Jour. Sci., XXVIII, 1859, p. 235.—Miller and Gurley, Bull. 8, Illinois St. Mus., 1896, p. 55, pl. 4, fig. 1.—Springer, Jour. Geology, XIV, 1906, p. 489.

*Taxocrinus multibrachiatus,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 49.

*Forbesiocrinus wortheni,* Meek and Worthen (not Hall), Geol. Surv. Illinois, V, 1873, p. 496, pl. 14, fig. 2; pl. 15, fig. 7.

*Forbesiocrinus speciosus,* Miller and Gurley, 16th Rep. Indiana Geol. Surv. (1888) 1890, p. 347, pl. 5, figs. 8, 9 (Author's ed. 1890, p. 27).

A medium-sized species very similar to *F. wortheni,* and perhaps only a variety of it. The relative size, number and proportions of plates, and spread of calyx are substantially the same. In general the calyx is rather more evenly rounded, and cross-section more obtuse; the arms are more deeply rounded and not so closely abutting, there being usually distinct elongated spaces for some distance above the bifurcations. Taking an average of 10 measured specimens, while the height to width of the whole crown as usually found is about the same, 1 to 0.7, the calyx to top of iBr is relatively higher, and the visible parts of the arms shorter; the ratio of height to width at greatest width, $IIBr_3$, is 1 to 1.8; that of height of calyx to crown is about 1 to 1.6, and height to width of calyx 1 to 1.2, as against 1 to 2 and 1 to 1.5 for the same ratios in the former species. Dimensions of a maximum and very small crown are:

Maximum: height of crown, 61 mm.; of calyx, 35; width, 40; base, 13.
Small: " " " 14 mm.; " " 9; " 10; " 4.

This species is found in the Indian Creek crinoid bed at several localities within a short distance along the creek of that name in Montgomery County, Indiana. That bed is in the eastern uplift of the Keokuk Group, separated from the western or Mississippi Keokuk by the Illinois coal field, to the east of which the Keokuk beds are considerably thinner and lose their predominant limestone character, becoming much more impure and argillaceous. By these differences in the waters of sedimentation the crinoid fauna was considerably modified, so that while the general type remains the same the majority of the species are not common to the two areas. For that reason this species may probably be maintained upon the slight differences above shown. The Indian Creek specimens have been found in considerable abundance and in good preservation. They occurred with other genera in small colonies, from one of which I have a fine series representing stages of growth from very young to mature, some of which are figured on Plate XXVIII. These are interesting to show the development of the interbrachial system from one or two plates to 15 or 20, according to the stages of growth. In some of these may also be seen a tendency among the plates of the anal side to develop a vertical series in the midst of the solid plates, with a line of weakness along its left margin.

Lyon and Casseday give the localities of this species as Clear Creek, Hardin County, Kentucky, and Washington and Montgomery counties, Indiana. Lyon prepared excellent figures which were never published, but were turned over to me when I acquired his collection. The type used for these figures is a weathered specimen in the very same preservation as those from the Indian Creek bed, and beyond all question it came from that locality, as there were also in Colonel Lyon's collection a number of other specimens from the same place, and he is known to have collected there in early days. But there was in his collection no specimen from any Kentucky locality labeled as, or which can be referred to, this species. There was however a specimen of *Onychocrinus ramulosus* from Hardin County labeled "*Forbesiocrinus multibrachiatus*," which probably accounts for the recording of that locality in the description.

The principal locality in Washington County, Indiana, has several species identical with that of Indian Creek, and the horizons are probably closely equivalent. A few specimens found in that vicinity may be referred to this species, among which is one figured on Plate XXIX, figure 4, and the type of Miller and Gurley's *F. speciosus* (*ibid.*, fig. 5). These authors also referred the form chiefly occurring at Indian Creek to their *F. washingtonensis,* distinguished by them from their earlier *F. speciosus* chiefly by the lack of anal plates in the latter, which they figured and described as having the interbrachial areas all alike (16th Report Geol. Surv. Indiana, p. 347, pl. 5, figs. 8, 9). On the type and only specimen (in the collection of Mr. Gurley now in the University of Chicago, No. 6267) the sutures were marked in ink as shown in their figures; but this was careless work, as a little cleaning showed the posterior basal truncate and having a large anal plate with others succeeding, as appears by my figure 5 of Plate XXIX; the arms are worn and flattened in the upper part, but it is generally much like the present species. The single large anal plate interposed above the basal is a variation occurring in some of these species which finally becomes constant in the Warsaw.

I have given two figures of Lyon's type, and it must be noted that it is flattened and crushed so that the two posterior rays are pushed together, concealing most of the plates of the anal side (Pl. XXVIII, fig. 1*b*); in the anterior view the arms look flatter than in the other specimens, but this is due to erosion. The specimen figured by Meek and Worthen, Geol. Surv. Illinois, volume 5, plates 14, figure 2, and 15, figure 7, as *Forbesiocrinus wortheni,* and now in my collection, is a much flattened and very mature example of this species from the typical locality.

The position of the small infrabasal is somewhat irregular, being in a few specimens anterior in position as in *F. saffordi.*

*Types.* Author's collection, except figure 5, Plate XXIX, which is in the University of Chicago.

*Horizon and locality.* Lower Carboniferous, Keokuk Group, eastern extension; Indian Creek, Montgomery County, Indiana, horizon below the Crawfordsville bed; also Washington County, Indiana.

### **Forbesiocrinus washingtonensis** Miller and Gurley

*Plate XXIX, figs. 1-3*

*Forbesiocrinus washingtonensis* Miller and Gurley, Bull. 8, Illinois St. Mus. Nat. Hist., 1896, p. 54, pl. 3, figs. 32, 33.—Miller, N. A. Geology and Palaeontology, 2d Appendix, 1897, p. 746, figs. 1356, 1357.—Springer, Jour. Geology, XIV, 1906, pl. 7, fig. 20.

The specimens described under this name are from the Canton beds of southern Indiana in Washington County, closely equivalent to those of Indian Creek, and may be only another variety of *F. wortheni.* They are somewhat smaller than the average of mature specimens in the two preceding species. The arms are flat and abutting, as in *F. wortheni,* but are much shorter and more delicate than in either. The calyx rises to a higher level, being to the crown as 1 to 1.4 in an average of five specimens, as compared with 1 to 2 and 1 to 1.6 in *F. wortheni* and *F. multibrachiatus* respectively. The greatest width is at about $\mathrm{IIIBr}_2$, instead of $\mathrm{IIBr}_3$ as in those species, so the ratio of height to width is about 1 to 1.5, as against 1 to 2 or 1 to 1.8. There is also a greater convexity of the plates, which are rounded from the suture lines, and not merely raised in the middle as in the Burlington species. In a maximum specimen the crown is 47 mm. high; calyx, 35; width at $\mathrm{IIIBr}_2$, 44; base, 13.

As already stated, Miller and Gurley described two species from this locality, the first being *F. speciosus,* which I have doubtfully referred to *F. multibrachiatus.* They distinguished it from the present species by its supposed lack of distinct anal side, and also by its having only 40 arms, against 60 in this; being an application of Miller's favorite dogma that the actual number of arms is an iron-clad specific character. Here the difference is due wholly to the height at which the arms happen to be folded in the fossil; if between the third and fourth bifurcation, forty will be visible from the exterior; if beyond the fourth, sixty or seventy or even more, according to the height of the infolding.

*Types.* Miller and Gurley's originals are in the University of Chicago; that of figure 3 in the author's collection.

*Horizon and locality.* Lower Carboniferous, Keokuk Group; Canton, Washington County, Indiana.

### **Forbesiocrinus pyriformis** Miller and Gurley

*Plate XXIX, figs. 6-7*

*Forbesiocrinus pyriformis* Miller and Gurley, Bull. 3, Illinois St. Museum, 1894, p. 47, pl. 4, fig. 1.

A large species. Crown elongate, pyriform, widest about IVBr, which is about the limit of the calyx. Height to width there 1 to 1.35; spread of calyx from base, 1 to 3.7; height of calyx to crown, 1 to 1.8; height to width of crown, 1 to 0.75. Calyx conical, with straight sides, cross-section circular. Base flush with top columnals. Calyx plates tumid, suture lines sinuous and impressed. iBr areas elongate and narrow with plates numerous. Arms rounded, short, well separated. General arrangement and proportion of plates as in the three preceding species, except that the lower brachials are somewhat longer, making the interbrachial areas also more elongated. Crown of large specimen, 60 mm. high; calyx, 35 mm.; width, 50 mm.; base at column facet, 13 mm.

The distinctly conical, circular calyx, and deeply rounded arms distinguish the species readily. It occurs in the Keokuk of Kentucky and Tennessee, where none of the preceding have been identified, and it has not been found in their regions. The species is rare, only four specimens being known, three of which are in the University of Chicago. Of these four specimens, three have the posterior basal truncate, followed by a single plate interposed between it and the usual two (Pl. XXIX, figs. *6b, 7b*), and that is probably the general rule in the species. Beyond the IIIBr the arms begin to taper quite rapidly, and infold about the fifth bifurcation. The zone of greatest width is at a higher order of brachials than in any other species, and the calyx is therefore relatively higher. The specimens are but little distorted and exhibit nearly the natural contour; the most perfect one, figures *7a, b*, is somewhat compressed vertically.

*Types.* The original of figures *6a, b*, is in the University of Chicago; that of figures *7a, b*, in the author's collection.

*Horizon and locality.* Lower Carboniferous, Keokuk Group; Muldraugh Hill, Kentucky, and White's Creek, Tennessee.

### **Forbesiocrinus greenei** Miller and Gurley

*Plate XXX, figs. 1-2*

*Forbesiocrinus greenei* Miller and Gurley, Bull. 9, Illinois St. Mus., 1896, p. 57, pl. 4, figs. 1, 2.
*Proguettardicrinus* ? *greenei*, Steinmann, Geol. Grundlagen der Abstammungslehre, 1908, p. 152, fig. 79.

A large species. Crown low globose, wider than high, contracting rapidly above IIIBr; greatest width at IIIBr$_1$, where height to width is 1 to 2.1; of calyx at upper limit of iBr, 1 to 1.4; spread of calyx from column facet, 1 to 4.4; height to width of crown, 1 to 1.2; height of calyx to crown, 1 to 1.2. Cross-section circular; side outline broadly curving. Base flush with top columnal. iBr small, numerous; areas long and wide, not depressed; rays not prominent. Calyx plates almost flat, and flush with the general curvature. Proportions of plates in the brachial series different from those of preceding species, RR and IBr being relatively shorter and wider, while IIBr and succeeding brachials are longer and narrower. Dimensions in millimeters of successive plates in characteristic specimens as follows: B, 4 x 9; R and IBr$_1$ and IBr$_2$, 4 x 11; IBr$_3$, 7 x 11; IIBr, 5 x 9; IIIBr$_1$, 5 x 7; IIIBr$_6$, 2.5 x 5; the IIIBr therefore diminish rapidly in width, thus leaving space for the extension of the iBr areas. Post. B followed by a single anal plate; above it two or three, and then the plates extend in ranges of four abreast to the height of IIIBr 2 or 3, and continue with diminishing width beyond the next bifurcation. Regular iBr areas extend above the highest IIIBr. Measurements of mature specimen: height of crown, estimated from the curvature and taper of rays, 52 mm.; calyx to top of iBr, 44 mm.; width at IIIBr$_1$, 61 mm.; base at column facet, 15 mm. Column large, continuous with base, and tapering as in other species.

The low, globose crown and flat plates distinguish the species readily from any other. The zone of greatest width is much lower than in the last species, and the crown contracts rapidly above that, as is indicated by the rapid tapering of the tertibrachs which in all the preceding species remain about the same width; this is partly compensated by the higher limit of the interbrachials which extend beyond the line of preservation in either of our specimens, and must have reached up between the quartibrachs. The species was described from a single specimen, but its characters have since been confirmed by the discovery of another one in better preservation from the same locality. Both are entirely rotund and give a good idea of the natural contour, but neither has any of the free arms preserved. The locality is in the extreme southern part of Indiana, and the horizon approximately the same as that of the last species, both occurring high in the Keokuk Group next to, or perhaps a part of, the Warsaw.

Steinmann's proposal to refer this species to a new genus, *Proguettardicrinus,* on account of superficial resemblance to the Jurassic *Guettardicrinus* has been discussed in the chapter on Phylogenetic Relations.

*Types.* The original type is in the University of Chicago; that of figures *2a, b* is in the author's collection.

*Horizon and locality.* Lower Carboniferous, upper part of Keokuk Group; Edwardsville, Floyd County, Indiana.

### **Forbesiocrinus saffordi** Hall

*Plates XXI, fig. 3; XXX, figs. 3-17; XXXI, figs. 1-10*

*Forbesiocrinus saffordi* Hall, Supp. Geol. Iowa, I, pt. 2, 1860, p. 87.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 3, 1886, p. 145.

A very large species. Crown low, pentagonal, wider than high, contracting rapidly above IIBr; greatest width at IIBr$_1$, where height to width is 1 to 2.8; of calyx at upper limit of iBr, about 1 to 1.4; spread of calyx at upper limit of iBr, about 1 to 1.4; spread of calyx from column facet, 1 to 4.7; height (estimated) to width of crown, 1 to 1.26; of calyx to crown, 1 to 1.1. Calyx deeply lobed; cross-section quinquelobate; side outline broadly curved. Base flush with top columnal. iBr areas concave, large and long, with large plates. Rays highly arched, broadly sloping to iBr areas. Calyx plates flush with the general curvature, those of iBr areas concave, those of the rays broadly rounded except the axillary IIBr, which is strongly tumid and abruptly curved at the distal end, so that the next order of brachials start at a lower level. Post. B truncate, followed by a single plate, and this by two or three abreast, increasing to four or more abreast for several ranges; regular iBr also becoming four abreast and extending to beyond IIIBr$_4$. Dimensions of successive plates in millimeters: B, 5 x 10.5; R, 3 x 14; IBr$_2$, 12 x 17; IIBr$_1$, 8.5 x 14; IIBr$_3$, 9 x 12; IIIBr, 3 x 7.5; those following, 2 x 7.5. Dimensions of mature specimen (Pl. XXXI, figs. 1*a, b*); height of crown estimated from curvature, 60 mm.; of calyx, 55 mm.; width, 76 mm.; base at column facet, 16 mm. Same measurements in young specimen (Pl. XXXI, fig. 2): 21; 17; 35; 8. A still younger specimen, preserved only to IIBr$_1$, is 7 mm. high by 18 mm. wide at that level; base, 5 mm. A detached base, indicating a crown still larger than the above mentioned specimen, is 18 mm. wide (fig. 3).

The strong lobation of the calyx is the special character of this species, in which it differs from all others. The great arching of the rays requires brachial plates of large size, as the above figures indicate, and it produces such wide spaces between that the interbrachials form broad concave areas, with relatively larger plates than in other species. Only at the end of the secundibrach series do the plates lose their even curvature and become tumid; and the abrupt distal rounding of IIBr$_3$ is a feature by which the species can be identified from any fragment preserving this part (Pl. XXXI, fig. 5). Not only is the abrupt change of the succeeding plates to a lower flat surface a very marked character but also the very great disproportion in their size. Unfortunately none of the specimens have the rays preserved beyond the tertibrachs, but from their great diminution in size I have no doubt that the arms became small and infolded at a level but little above that shown in figure 1*a* of Plate XXXI.

The truncate posterior basal, with one plate following instead of two, has become a constant character in this species, being uniform in all the 25 or more specimens showing these parts; only one from the same locality (Pl. XXX, fig. 17) has an angular basal, and it is probably not of this species. There is also a peculiar modification in the orientation of the small infrabasal, which is almost uniformly located at the anterior instead of the right posterior as usual in the Flexibilia; among the numerous specimens only one has it in the regular position, while in two it is at the left posterior (Pl. XXX, fig. 10); in one of the latter this plate is larger than either of the other two. Being the last known survivor of the genus, strongly divergent from the usual form of the calyx, and very abundant at the typical locality, the species presents just the conditions for variation even in characters belonging to the entire group.

The species was described by Hall in the Supplement to the Geology of Iowa, without illustration, from a single specimen found by Professor J. M. Safford, formerly State Geologist of Tennessee, in the upper part of the Keokuk exposures on White's Creek, near Nashville, Tennessee. His description was very clear, and enabled me to recognize the species readily from an unlabeled cast in the Museum of Comparative Zoology, which afterwards proved to be taken from the type. No other specimens were found at the original locality, and the type, packed away after Professor Hall's description of it, remained inaccessible until recently. In the meantime a considerable number of fragmentary specimens were found in the debris of the so-called Warsaw beds at and near Spergen Hill, associated with *Pentremites conoideus* and *Batocrinus icosidactylus,* which upon comparison with the type have proved to belong unquestionably to this species. Only two, and these quite small, have any considerable part of the calyx intact, but among the detached bases are some even larger than that of the type. The specimens were in a loose matrix readily removed by washing, and have furnished important information as to the structure of the inner floor of the calyx, and the axial canal, which is discussed in the remarks on the genus. A representative series of them are figured on Plates XXX and XXXI.

These specimens also furnish fine examples of the mode of union of the calyx plates in this genus; that of the brachio-interbrachial sutures with their numerous small, interrupted ligament fossae on Plate XXXI, figures 6*c, d,* 7*d,* and that of the brachial articulations with their paired muscle-fossae, figure 7*c;* also for both, figures 10*a, b*. In figures 3*b, c* the articulation on the radial is unpaired. Figures 6*a, b* also show the manner in which interbrachials grew from the inside of the calyx to fill up space as the visceral mass increased; comparison of the lettered plates in the two figures will show how much larger these plates are at the interior than at the exterior, while the numbered plates show how the reverse is the case with the brachials, which, being the first developed, are gradually wedged apart from the inside by insertion of the newly forming interbrachials.

Unfortunately none of the specimens have the arms preserved, the highest plate of the calyx remaining being $\mathrm{IIIBr}_6$. From the great width of the calyx, and the rapid contraction and small size of plates above the secundibrachs, it is probable that the crown was relatively very low and short armed, as in *F. greenei*. In the calyx alone, however, it is by far the largest known crinoid of the Flexibilia, the type specimen being about three inches in diameter; and there are fragments indicating the existence of others at least half an inch wider.

*Types.* In the author's collection, the original of Plate XXXI, figures 1*a, b,* having been presented to me by Professor Safford when rediscovered a few years ago.

*Horizon and locality.* Lower Carboniferous, highest part of the Keokuk limestone; White's Creek, Tennessee, and at the base of the so-called Warsaw beds at Spergen Hill and vicinity, Indiana.

## Family ICHTHYOCRINIDAE Angelin

(Emend. Wachsmuth and Springer)

Sagenocrinoidea with infrabasals horizontal, not appearing externally and taking no part in the calyx wall, sometimes disappearing by atrophy. Crown elongate or rotund. Rays widening from radials up, in close contact, usually interlocking or abutting throughout or above interbrachials.

### Analysis of the Genera

- I. *Rays in contact all around.*
  - Arms dichotomous, interlocking. IBr 2.
    - No anal or iBr. Post. B not differentiated.
      - RA in form of R, under r. post. R. . . . . . . . . . . . . . . . . . . . . . . . . . . .Ichthyocrinus.
      - No RA.
        - Post. B not differentiated . . . . . . . . . . . . . . . . . . . . . . . . . . .Metichthyocrinus.
        - Post. B elongate . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .Synaptocrinus.
- II. *Rays in contact except at anal side.*
  - Arms dichotomous, interlocking. IBr 2.
    - RA in form of R, under r. post. R.
      - Anal *x* alone or followed by others.
        - Post. B truncate. (IBB unstable, often appearing beyond the column) . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .Clidochirus.
        - Post. B not differentiated, and not touching anal *x*. . . . . . . . . . .Cleistocrinus.
- III. *Rays above radials partly or wholly separated.*
  - RA not identifiable, or wanting.
    - Arms dichotomous, usually abutting over iBr.
      - Anal *x* followed by others in single series.
        - iBr few, usually in single series. IBr 3. . . . . . . . . . . . . . . . . . . . .Euryocrinus.
        - iBr numerous, in more than one series. IBr 2. . . . . . . . . . . . . . . .Amphicrinus.
    - Arms heterotomous.
      - iBr few or absent.
        - Anal *x* followed by others in more than one series, suturally connected at sides . . . . . . . . . . . . . . . . . . . . . . . . . .Dactylocrinus.
        - Anal *x* suturally connected at sides and with post. B followed by others in series, forming a tube. . . . . . . . . . . . .Synerocrinus.
        - No anal. Post. B not differentiated. . . . . . . . . . . . . . . . .Wachsmuthicrinus.

The rudimentary and more or less unstable condition of the infrabasals is the chief diagnostic character of this family. These plates, which in the Lecanocrinidae form an essential part of the calyx, are here so completely withdrawn from the exterior that in specimens with the column attached there is no evidence of their existence. In typical genera they form a mere vertical plug,[1] of no functional importance; and in several species this plug is completely resorbed, leaving an open space of substantially its own form and size. Correlated with the foregoing is another character equally constant, which gives to the genera of this family a certain conspicuous facies by which they can usually be recognized from any fragment containing the lower portion of a ray; this is the relatively small size of the radial plates. With this is combined a close abutting or interlocking of the rays either from their origin or above the interbrachials when present, producing a continuous wall for several series of brachials. Consequently the rays are fan-shaped, widening from the radials up. The presence of interbrachials does not materially alter this peculiar aspect. There is, therefore, in this family in its most extreme form that non-differentiation of the calyx which to a greater or less degree characterizes the order Flexibilia, the arms being mere continuations of the lower brachial series, which pass into them without any apparent change except gradual reduction in size.

By reason of the correlation of these characters the Ichthyocrinidae form a remarkably compact, well-defined family group, which is sharply distinguished from the two preceding, although it includes both rotund and elongate forms. Only one of the genera, *Clidochirus,* might be confounded with the Lecanocrinidae, owing to variability in size of the infrabasals among the species; while *Synerocrinus,* although thoroughly typical as to this character, on account of its weak anal side is a transition form toward the Taxocrinidae.

There is in this family a very notable suppression of anal structures, the pentamerous symmetry of the calyx being but little modified by them. In four of the genera the posterior basal is not differentiated, and in a fifth, *Synaptocrinus,* although elongated it is not followed by any anal plate. In one, *Amphicrinus,* the posterior interradius is smaller than the other four. The radianal is found in only three genera (Silurian and Devonian) in the strictly primitive position as an inferradial, and is so inconspicuous that its existence as a calyx element was never recognized until I pointed it out in 1906; it is most prominent in some species of the otherwise aberrant *Clidochirus.* The oblique form of radianal is not found at all. Two Silurian, two Devonian, and all the Carboniferous genera are without any identifiable radianal.

The dichotomous arm structure prevails in a large majority of the genera, but in the three in which the heterotomous type occurs it attains the most perfect stage with conspicuous main rami fringed with subordinate ramules.

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[1] Text-fig. 11, p. 117.

The family ranges from the Silurian with three genera, through the Devonian, culminating in the Lower Carboniferous with six genera, one of which passes up to the Lower Coal Measures (Pennsylvanian), making it the latest survivor of the Flexibilia.

Geographically the family is equally well distributed; two genera, *Cleistocrinus* and *Synerocrinus* are restricted to Europe; two, *Metichthyocrinus* and *Synaptocrinus,* to America; while the other six occur in both hemispheres.

*Geological and Geographical Distribution*

**Number of known species**

(Open figures indicate American, those marked ( ) European)

| Formation | | | Ichthyocrinidae | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| General | American | Approximate European Equivalents | Ichthyocrinus | Cleistocrinus | Clidochirus | Synaptocrinus | Dactylocrinus | Euryocrinus | Metichthyocrinus | Wachsmuthicrinus | Synerocrinus | Amphicrinus | Total |
| Carb. | Pennsylvanian | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 1 | |
| Lower Carboniferous | Kaskaskia | Hurlet<br>Moscow | ... | ... | ... | ... | ... | ... | ... | ... | ...<br>(1) | ...<br>(1) | |
| | St. Louis | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | |
| | Keokuk | ... | ... | ... | 1 | ... | ... | ... | ... | ... | ... | ... | |
| | Burlington | Mountain limestone | ... | ... | ... | ... | ... | ... | 3 | 5 | ... | ... | |
| | Kinderhook-Waverly | | ... | ... | ... | ... | 1 | 1<br>(3) | ... | ...<br>(1) | ... | ... | 18 |
| Devonian | Chemung | Upper | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | |
| | Hamilton | Middle | ... | ... | ... | 1 | (2)<br>2<br>(1) | 1 | ... | ... | ... | ... | |
| | Helderbergian | Lower | 1 | ... | 2 | ... | ... | ... | ... | ... | ... | ... | 10 |
| Silurian | Niagaran | Wenlock | 3<br>(5) | ...<br>(1) | 1<br>(1) | ... | ... | ... | ... | ... | ... | ... | |
| | Medinan | ... | 1 | ... | ... | ... | ... | ... | ... | ... | ... | ... | 12 |
| | American species | 24 | 5 | ... | 4 | 1 | 3 | 2 | 3 | 5 | ... | 1 | |
| | European species | (16) | (5) | (1) | (1) | ... | (3) | (3) | ... | (1) | (1) | (1) | |
| | Total species | 40 | 10 | 1 | 5 | 1 | 6 | 5 | 3 | 6 | 1 | 2 | 40 |

## **ICHTHYOCRINUS** Conrad

*Plates XXXII-XXXVI*

*Ichthyocrinus* Conrad, Jour. Acad. Nat. Sci. Philadelphia, VIII, 1842, p. 279.—D'Orbigny, Prodr. Pal. Stratigraphique, I, 1849, p. 46; Cours Elem. Pal. et Geol. Strat., II, 1851, p. 144.—Hall, Nat. Hist. New York, Pal. II, 1852, p. 195; Geol. Iowa, I, pt. 2, 1858, p. 557.—McCoy, Syn. Brit. Pal. Fossils, 1854, p. 54.—Roemer in Bronn, Lethaea Geognostica, I, 1852-54, p. 237.—Pictet, Traité Paleontologie, IV, 1857, p. 319.—Bronn, Klassen Ord. Thier-Reichs, II, 1860, p. 231.—Quenstedt, Handb. Petrefaktenkunde, 1867, p. 737; Petref. Deutschlands, IV, 1876, p. 515.—Beyrich, Monatsber. Akad. Wiss. Berlin, 1871, p. 42 (Trans. in Ann. and Mag. Nat. Hist., (4) VII, p. 403). Salter, Cat. Cambrian and Silurian Fossils, 1873, p. 126.—Angelin, Icon. Crin. Sueciae, 1878, p. 13.—Wachsmuth and Springer, Proc. Acad. Nat. Sci. Philadelphia, 1878, p. 252; *ibid.*, 1888, p. 353; 1890, p. 387; Revision Palaeocrinoidea, pt. 1, 1879, p. 33; *ibid.*, pt. 3, 1886, p. 143.—Von Zittel, Handbuch Palaeontologie, I, 1879, p. 355; Grundzüge Palaeontologie, 1895, p. 138.—Miller, N. A. Geol. and Pal., 1889, p. 256.—Zittel-Eastman, Textbook Palaeontology, 1896, p. 163 (2d Ed., 1913, p. 204).—Bather, Proc. Zool. Soc. London, 1896, p. 998; Natural Science, XII, 1898, p. 341; Ann. and Mag. Nat. Hist., (7) VI, 1900, p. 112; Treatise on Zoology (Lankester), pt. 3, 1900, p. 188.—Weller, Bull. IV, Chicago Acad. Sci., I, 1900, p. 145.—Springer, Amer. Geologist, XXX, 1902, p. 94; Jour. Geology, XIV, 1906, p. 475.

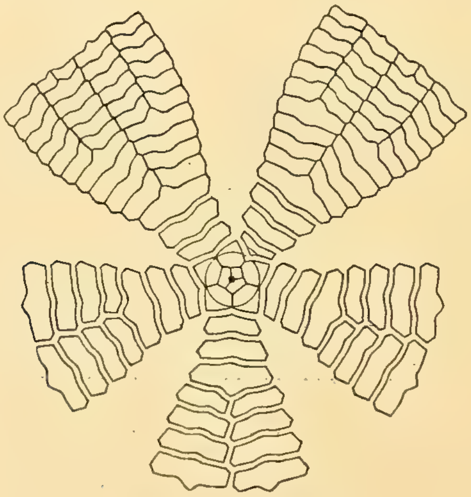

FIG. 36. *Ichthyocrinus*

Ichthyocrinidae with rays in contact all around. Crown elongate, expanding from radials up. Infrabasals entirely within ring of basals, sometimes resorbed. Posterior basal not differentiated. Radianal in primitive position under right posterior radial, touching right anterior radial; smaller than, and of similar form to, other radials. No anal or interbrachial plates. Primibrachs two. Rays widening from radials up. Arms dichotomous, interlocking to at least the second subdivision, closely abutting above that; they are mere continuations of the ray divisions without line of demarcation. Column proximally enlarging, usually to the diameter of the base.

*Genotype. Ichthyocrinus laevis* Conrad.

*Distribution.* Silurian and Devonian; Europe and North America.

The genus *Ichthyocrinus* is a typical and perhaps the most characteristic representative of the Crinoidea Flexibilia, giving the name to the group in which their peculiar characters were first recognized as the basis of a large division by Wachsmuth and Springer. It was established by Conrad[1] in 1842, and the type species, *I. laevis*, described. His diagnosis, if such it might be called, was as follows: "Column round, smooth; canal small and round; scapulae with the margins of the articulations parallel, and somewhat imbricated."

This gave but little insight into the essential characters of the genus, but the accompanying figure of *I. laevis* left no doubt as to what was intended to be described. This form, although then first designated as a distinct genus, was not new to paleontology. It had been observed at an early day as one of a few distinct and leading types of fossil crinoids in England, which afterward became the representatives of as many well-marked genera and families. It is rather curious that one of the earliest published figures of the complete crown of a paleozoic crinoid should be that of a fine specimen of this extremely rare genus. John Ellis[2] in 1762 gave an "Account of an *Encrinus*, or Starfish, with a jointed stem, taken on the coast of Barbadoes, which explains to what kind of Animal those fossils belong called Starstones, Asteriae, and Astropodia, which have been found in many parts of this Kingdom"; and in connection with a finely engraved drawing of a recent West Indian pentacrinite he figured for comparison "two curious fossils" found at Pyrton-passage in Gloucestershire. One of these (pl. 13, Fig. B), showing "all the ramified arms of the head closed up together," is a very characteristic *Ichthyocrinus*, perhaps *I. pyriformis*, probably enlarged in drawing.

Ellis's figure was copied and the type discussed by Parkinson[3] in 1808, as the Gloucestershire pentacrinite, to which he gave the name of the "Fig Pentacrinite" (p. 274). He also (*op. cit.*, pp. 194-6, Pl. XV, fig. 9) figured and described another specimen belonging to some genus of the Ichthyocrinidae from Derbyshire, as the Derbyshire encrinite, which he called the "Cap Encrinite," said to be derived from the great limestone formation of the north of England since known as the Mountain limestone. Parts of this, as Parkinson stated, are filled with amazing quantities of crinoidal bodies and other marine remains, and he evidently considered all the crinoidal remains as belonging to a single form peculiar to that region, as he figured and discussed several unrelated fragments under the same name. The crown as figured (Pl. XV, fig. 9) represents an Ichthyocrinoid with broadly rounded base, no interradials, and the arm divisions unequal. In the text the author states that this form is "characterized by its rounded and pyriform figure." At another place (p. 271), when discussing the Gloucestershire pentacrinite, he speaks of the arm division in that form as "closely resembling the divisions that take place in the arms of the Cap encrinite, a first division taking place at about the third articulation, and the fingers which are thus formed being repeatedly subdivided in a dichotomous manner." Parkinson was much impressed with the distinctness of the type, and wanted to call it the "pyriform encrinite," but was embarrassed by the fact that there was another one otherwise widely different which was also pear-shaped (*Apiocrinus*); so he called the latter the "Pear Encrinite," while to a third equally pronounced type (*Eucalyptocrinus*) he gave the name "Turban Encrinite"; and as before stated called the Derbyshire form the "Cap Encrinite." In view of the doubt as to some of the essential structures I have been unable to locate this last form generically. Taking the figure strictly as it appears, it would not fall under any known genus. With a more dichotomous arm-branching it would come nearest to *Metichthyocrinus*, which has not otherwise been observed in British rocks. And if we also assume some interbrachial structures not shown in the figure, it might belong to *Euryocrinus*, a form which is typically from the same Mountain limestone area in Yorkshire. Considering the author's emphasis upon the pyriform shape, and the uncertainty about the arm branching, there is a suggestion of *Ichthyocrinus;* which involves the possibility of the specimen being from the Silurian of the

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[1] Jour. Acad. Nat. Sci. Philadelphia, vol. 8, p. 278.

[2] Philos. Trans. Roy. Soc. London, vol. 52, p. 357, pl. 13.

[3] Organic Remains of a Former World, vol. 2, pp. 258, 270, 271, Pl. XIX, fig. 2.

Wenlock area, as the locality of its occurrence is not stated, although its owner called it the "superior part of the Derbyshire encrinite."

In 1839 Phillips[1] described and figured as *Cyathocrinites pyriformis* a well-marked specimen somewhat similar to that of Ellis (Parkinson's pl. 19, fig. 2). He recognized, however, its strongly distinctive structure, and stated that it "ought probably to constitute a new genus," pointing out as its characters "the great width, general equality and lateral union of the plates, till the arm divisions amount to twenty."

Hall[2] in 1843 referred Phillips's species to Conrad's genus, and expressed the opinion that the species described by the two authors from England and America respectively were identical.

D'Orbigny[3] in 1849 accredited the genus *Ichthyocrinus* to Conrad, defining it as follows: "Calice composée de quatre séries de pièces. Cinq pièces basales." His idea of its character was rather indistinct, for while following Hall in referring to it *C. pyriformis* along with *I. laevis,* he included also several species now ranged under *Gissocrinus,* in which the characters pointed out by both Phillips and Hall as peculiar to the new form are wholly wanting.

Hall[4] took up the discussion of the genus again in 1852 in connection with a more elaborate description of *I. laevis,* with ample illustrations showing new and important details. After quoting Conrad's generic definition, which he thought not sufficiently precise, he stated that the cup consists of five small, triangular pelvic plates, succeeded by three scapular plates followed by two or three subdivisions; and he added: "The base of the cup, when the column is separated, presents a tripetalous impression, which is probably of generic importance. This genus . . . . possesses peculiarities of high interest, showing its relations to crinoids with three pelvic plates." This is the first allusion in the literature of this group to a dicyclic base. He confirmed this statement in 1858[5] in his generic formula, where he said there were "sometimes three other rudimentary plates within the five basal plates."

M'Coy[6] in 1854 gave a description of *Ichthyocrinus* in considerable detail, crediting it to Conrad in conjunction with D'Orbigny, without whose suggestion he thought "the figure and description of Mr. Conrad would not have been definite enough to establish this genus";—though wherein D'Orbigny's definition contributed to its elucidation is difficult to see. M'Coy defined the generic characters to be: column round, the calyx composed of 5 pelvic plates (Basals); 5 first, second, and third primary radials, the last supporting two rows of secondary radials of 4 joints each, etc. He added however the important observation that "the absence of interradial plates separates this genus from *Taxocrinus*"; this was confirmed by Salter in his Catalogue of 1873, as the sole difference between the two genera.

Bronn[7] in 1860 defined the genus as irregular, having 5 basals, no subradials, 4, 1 x 3 radials, and no anals nor interradials. Neither M'Coy nor Bronn made any allusion to the existence of five undeveloped pelvic plates (infrabasals), nor had Roemer done so in Bronn's Lethaea Geognostica in 1856.

Angelin[8] in 1878 recognized three basals and five parabasals, the former sometimes obsolete; but he introduced a new complication by giving also one anal plate between the lower radials—a statement not warranted by any of his specimens.

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[1] In Murchison, Silurian System, vol. 2, p. 672, pl. 17, fig. 6.

[2] Geology of the Fourth District, New York, p. 112.

[3] Prodrome de Paléontologie, vol. 1, p. 46.

[4] Nat. Hist. New York, Paleontology, vol. 2, p. 195.

[5] Geology of Iowa, vol. 1, pt. 2, p. 557.

[6] British Palaeozoic Fossils, p. 54.

[7] Klassen und Ordnungen des Thier-Reichs, Bd. 2, p. 231.

[8] Icon. Crin. Suec., p. 13.

In 1878 Wachsmuth and Springer,[1] in a paper on Transition Forms in Crinoids, discussed the genus in relation to some newly discovered Lower Carboniferous specimens which agreed with it in a striking manner in everything except that they had well developed interbrachial plates. For this reason we felt compelled to modify the conception of the genus theretofore obtaining so as to include such forms as these. Inasmuch as the author of the genus had not given a diagnosis from which any exact limits could be determined, it was apparent that its definition was a mere outgrowth of the individual opinions of the subsequent writers who had treated of it. Having as we thought found the above modification an imperative necessity consequent upon the discovery of new material, we were in turn much perplexed by the fact that this would leave the three genera, *Ichthyocrinus, Taxocrinus* and *Forbesiocrinus,* without any very essential structural differences to separate them, and we found no way out of the dilemma except to consider *Taxocrinus* and *Forbesiocrinus* as subgenera.

Further consideration, however, in our Revision of the Palaeocrinoidea, pt. 1, p. 43, led us to recognize the distinctness of the three genera for reasons there pointed out, but we still retained the species with interbrachials (*I. nobilis*) under *Ichthyocrinus.* The specimens of this Lower Carboniferous species then known to us did not disclose the anal side, which we still supposed to be not distinctive; and in the generic description given by us in the Revision, in addition to the three "underbasals," five basals, and details of radials and arms there stated, we noted the "almost equilateral pentamerous symmetry" of the body; and added "the most striking feature of this genus, by which it is easily recognized, is its symmetrical, equilateral figure, and this pervades the whole body."

In addition to the foregoing it had then been discovered and pointed out by us (*op. cit.,* p. 31) that in this genus, in common with several others, the plates of the calyx and rays were joined together by a peculiar loose articulation, producing a flexibility in the calyx which sharply distinguished this association of genera from the other crinoids, and caused their separation as a distinct family then called Ichthyocrinidae, but afterwards extended by us into a grand division under the name Articulata,[2] for which Von Zittel[3] afterward substituted the preferable term Flexibilia.

The foregoing definition of the genus was followed substantially by Weller[4] and by Bather;[5] but Von Zittel[6] still adhered to the exclusion of interbrachials.

Until that time the distinctive conception of the genus as usually held—aside from the pliant calyx and abutting arms—was that of a crinoid with perfect pentamerous symmetry in the calyx. The discovery by me of more perfect specimens of *I. nobilis,* however, disclosed the fact that this species has a perfectly distinct anal side, with plates in a tube-like series like *Taxocrinus;* and on this account in 1902[7] I proposed for it a new genus, *Parichthyocrinus.* The removal of this species restored the parent genus to its former position with rays in lateral contact, without the intervention of anal and interbrachial plates, and, as was still supposed, with perfect pentamerous symmetry. It is true that Weller,[8] in his redescription of *I. subangularis,* had noted the fact that there were "costals two, rarely three, in each ray"; but that was considered to be a mere irregularity such as was supposed to pervade the whole group, and not as contradicting the idea which until then prevailed that this genus was the simplest of them all, having a perfectly symmetrical calyx without anal or interbrachial plates, and ranging in this simple form from the Silurian to the Carboniferous.

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[1] Proc. Acad. Nat. Sci. Philadelphia, p. 252.

[2] Revision of the Palaeocrinoidea, pt. 3, sec. 1, 1885, p. 6.

[3] Grundzüge der Palaeontologie, 1895, p. 137.

[4] Chicago Acad. Sci., Bull. 4, pt. 1, 1900, p. 145.

[5] In Lankester's Zoology, pt. 3, 1900, p. 188.

[6] Op. cit., p. 138.

[7] American Geologist, vol. 30, p. 96.

[8] Chicago Acad. Sci., Bull. 4, 1900, p. 146.

Such was the state of opinion when I discovered and pointed out in 1906[1] that in all the Silurian species of this genus there is an extra plate in the right posterior ray situated directly underneath the radial, and identified this plate as the Radianal in its primitive position as an infer-radial, just as it had been found in the Taxocrinoid genus *Temnocrinus,* and in the Inadunate genus *Dendrocrinus.*

This discovery made it necessary to remove the Carboniferous species, in which the radianal was found to be absent, under the name *Metichthyocrinus,* thus leaving *Ichthyocrinus,* so far as then known, a purely Silurian genus.

The history of this genus is an instructive example showing how, under the influence of prevalent notions and modes of interpretation of fossils, palpable facts having a most important bearing upon their zoological relations may be overlooked or ignored throughout a series of apparently careful researches by conscientious naturalists extending over half a century. The existence of the extra plate in one ray has been plainly evident ever since Hall published his fine figures of *I. laevis* in 1852; but from the point of view from which paleontologists considered it this fact had no significance, and was treated as a mere irregularity. It comes to the front now as the firm basis for a much desired separation between the Silurian and Carboniferous species, which I think must gain the approval of every careful student of the crinoids.

Throughout all the shifting of opinion just recited touching the definition of the genus, there is one reliable fact, viz. that we know to a certainty the form upon which Conrad founded the genus, which he figured as his typical species, and which his contemporary, Hall, had in mind when he brought together under it the American and British species as identical. And it is a satisfaction to find, as the final outcome of these various changes, that we are led by a plain and evident road back to the original species as the sure and unmistakable foundation of the genus.

The most characteristic feature of *Ichthyocrinus* is the complete absence of interbrachial structures, either anal or otherwise. This fact, together with the generally small size of the basals, produces a rapid increase in the width of the primibrachs from the radials up. There is nothing that can properly be called a calyx such as is recognized in crinoids generally. The basals, even when the largest, are not entirely free from the stem, and the radials are much smaller than the succeeding primibrachs, being sometimes also partly covered by the stem. The main constructive energy of this crinoid, so far as can be seen from the dorsal side, seems to have been directed toward the brachial system, which has an uninterrupted sweep from the very base of the crown to its summit, giving to the fossils of the genus a habitus so peculiar that it can be recognized from the smallest fragment of the calyx. This peculiarity is shared by *Parichthyocrinus* and *Metichthyocrinus* from the Carboniferous, so that a view of the posterior ray, or a knowledge of their geological position, is necessary to distinguish them. *Clidochirus* has something of the same aspect, but less pronounced by reason of the larger basals and the presence of an anal plate; and it prevails to a greater or less extent throughout the family Ichthyocrinidae.

The interlocking of the rays and their divisions is also a very marked character of this genus. Beginning with the primibrachs there is a slight irregularity in the height of the corresponding plates of adjacent rays, so that one suture stands at a little higher level than the opposite one. Thus the plates of the same ranges alternate somewhat with each other, and the vertical lines of junction between the rays and their subdivisions are not straight, but somewhat zig-zag. This structure produces a firm interlocking of all these plates up to and including most of the third order, beyond which the arms gradually become free, though usually still abutting. The height to which the interlocking continues varies with individual growth, and perhaps with different species; it is less in young individuals than in those of mature age. There is, however, no point where the arms can be said regularly to become free as in many other crinoids, or can be distinguished from the ray divisions of which they are mere direct extensions. In other words, we cannot tell from the dorsal side where the calyx ends and the free arms begin. This is a character largely prevalent throughout the group, but it is especially marked in *Ichthyocrinus.* From this interlocking of the rays, and the manner in which the arms are usually found tightly folded over the tegmen, it might be supposed that the spread of ventral surface for the gathering of food was not very wide. It is evident however, that the arms were much longer than would be judged from the general appearance of the specimens; they become very slender, and are coiled at least two or three times after disappearing from view on the outside (Pl. XXXV, fig. 16).

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[1] Journal of Geology, vol. 14, pp. 475 *et seq.*

In its basal structure *Ichthyocrinus* exemplifies to the extreme the character upon which the family is now defined. The infrabasals, and to a considerable extent the basals, have ceased to form a part of the calyx wall, and there is a tendency in the former to atrophy; they are very small, always completely covered by the top columnal, and in one species, probably two, they have entirely disappeared, leaving in their place a large opening communicating with the chambered organ. In considering this character Angelin's figures must be altogether ignored; his plate 22, figure 22, of *pyriformis,* shows prominent and projecting infrabasals, whereas there is nothing of the kind in the specimen (Pl. XXXII, fig. 9*a,* herein).

The axial canal entering the stem from the base is obtusely pentagonal in outline, its angles radial in position; immediately inside the calyx it enlarges and projects above the floor of the cavity in a raised funnel-shaped rim the lobes of which, so far as observed, coincide with the basals and are therefore interradial (Pl. XXXIII, figs. 9*b, c;* text-fig. 1*a*). In the specimen illustrated, which is the only one showing the inner floor of the base, the funnel is not perfect all around owing to injury, but it probably surmounted all the basals with five lobes, upon each of which a shallow channel passed down over the inner edge of a basal toward the infrabasals. Comparing this with the similar funnel of *Forbesiocrinus saffordi* shown in several figures on Plate XXX, it will be noted that there it is exteriorly trilobate, coinciding with the three infrabasals from whose inner edges it rises; but that the lobes are divided by septa in such a way that the five resulting channels pass downward through the infrabasals interradially.

In *Ichthyocrinus,* the infrabasals being too minute to afford space for such structure, it is formed upon the edges of the five basals, and is therefore five-lobed. In this shape at the level of the basals it doubtless lodged the chambered organ, from which the axial cords passed down toward the stem. Being interradial in conformity with the orientation of the basals, they would be expected to continue in that position; but such is not the case. The channeled lobes of the funnel are bounded by very thin septa, which instead of being straight curve to the right sufficiently to make the channels in the radii of the stem lumen radial in position. In other words, the axial canal in passing from the basals to the stem has undergone a revolution of 36 degrees in order to become radial; whereas in *Forbesiocrinus saffordi* the channels are interradial where the funnel originates on the infrabasals and continue so into the stem.

When the original figure 9*c* was drawn the exact structure of the funnel was not understood, and the extremely thin septa were overlooked. These may now be seen in text-figure 1*a* (p. 35) of the interior, drawn with sufficient enlargement to show how the septa twist to the right as they pass downward. This evidence of an actual revolution in the position of the axial canal may help to explain the perplexing variations of its orientation in the few genera where it is known. The rarity of specimens in which it can be traced, except in one species, renders generalization upon this character uncertain.

The basals are never entirely exposed to view; they are always more or less covered by the column, and therefore their lower angles cannot be seen from the exterior. Hence in species where they are the largest we only see them as pentagons; in others where they are hidden more deeply under the column the vertical sutures disappear, and only very small triangular points remain; and in still others the basals cannot be seen at all, the radials resting directly on the column.

The radianal, resting in the angle formed by two infrabasals and in contact with a radial at each side and above, is necessarily pentangular, but this is not always fully disclosed in a lateral view. It is disproportionately small as compared with the succeeding plate, or with the corresponding radial in other rays; it has frequently the appearance of an ill-formed plate, either imperfectly developed or in process of elimination; it often lies below the line of the radials in the other rays, and is entirely covered by the column. See various forms of this plate on Plate XXXV.

The number of primibrachs seems constant except for an extra one in a single Swedish specimen. The secundibrachs are generally four, with variations of from three to five in occasional rays, but in one species the number seems constant at three. Beyond this the number of brachials in the successive divisions is inconstant; the branching loses its perfectly isotomous character and becomes more or less unequal. The number of tertibrachs is greater in the outer rami, and varies between 7 and 12, rarely exceeding the latter, and there are other bifurcations beyond them.

We know nothing of the tegmen from actual observation, but there is no reason to doubt that it is essentially similar to that of the other genera of this group in which it has been found—that is, a flexible disk with the ambulacra running along the surface from the open mouth to the arms.

The calyx wall had a certain amount of pliability, combined with strength. In the upper part the plates are relatively deep, or thick dorso-ventrally, and fit together like stones in an arch. This arch-like construction of the calyx, with the arms closely folded over it, must have given to the crown great strength in the upper part to resist compression, since notwithstanding the pliant test many of the specimens as found are fairly rotund.

The column has the general structure which prevails in the columns of the majority of genera of this group, and differs scarcely any among the species in which it is known. It is composed throughout the greater part of rather long ossicles alternating with short ones until near the junction with the calyx, where it gradually widens to nearly or quite the diameter of the base, covering the infrabasals and in some species the basals, radianal and part of the radials. In the expanded portion next to the calyx, and sometimes for a little distance below it, the columnals are very thin, and equal. Maximum length of column as shown by two complete specimens obtained after the plates were printed 23 cm.

*Ichthyocrinus* is one of the most widely distributed genera of the Crinoidea, being found in various American states from Tennessee to New York, and in England, Sweden and Bohemia; but its geological range is not great, being limited chiefly to the Silurian but with two species in the Lower Devonian. Its direct successor was *Metichthyocrinus* in the Carboniferous, evolved by the elimination of the radianal through intermediate stages which have not yet been discovered.

In a genus like this, where the interbrachial system is wholly undeveloped and the brachial arrangement so simple as to admit of but little variation, characters for the satisfactory definition of species are not readily discerned. In all the original specific descriptions scarcely anything was given beyond the characters pertaining to the whole group, or to the genus; so we get very little assistance from any of them. The difficulty is heightened by the paucity of the specimens and their too frequently imperfect condition. *Ichthyocrinus* has always been one of the rarest forms of fossil crinoids, and collectors have considered themselves fortunate to have any examples of it, however imperfect. The figures given herein represent substantially all the important specimens that have been found during the past century in England, Sweden and America, with the exception of some belonging to *I. pyriformis* from Dudley which is somewhat better represented than other species, and the casts of *I. corbis* from Chicago.

The form and proportions of the crown are not as serviceable characters in practice as they should be, for the reason that in so many cases the specimen as found is distorted or flattened by pressure, or only the lower part remains. The restorations I have made, based on careful measurements of several specimens, show how erroneous an impression one may gain from a flattened individual. Some range of variation is to be expected in this character, but it is not so great in this genus as I had supposed. Measurements yielding certain relative proportions show an average uniformity in the modifications of general form which is of service in the separation of species.

The sinuous outline of the transverse sutures, which has been relied upon in some cases as a specific character, must be left out of consideration; because as has already been shown in regard to the group in general, while the sutures are more or less wavy on the exterior, they are perfectly straight a short distance inward; so that by a little weathering of the fossil the sinuosity is effaced and the suture appears straight. The so-called "patelloid plates," of which so much has been said in various descriptions, are only an incidental feature of this structure, where the downward projecting lip or process at the middle of the proximal edge of a plate has become cracked by contraction of the rays or by pressure in fossilization, giving the appearance of separate plates.

The wavy sutures form a marked surface character in the genus, and they are probably somewhat more pronounced in some species than others. I doubt if there is any species entirely without them. In connection with this there is a peculiarity of the sutures in most species—probably in all to a greater or less extent—which Conrad called "imbricated." The upper margin of the plates is raised into a more or less abrupt step, which gives them the appearance of overlapping the edge of the following plate, and it was this fish-scale-like resemblance which suggested the generic name.

The relative development of basals and infrabasals seems to afford some tangible ground for distinction; and so also does the surface ornament. The latter character is often obscured by wear or weathering, but by careful examination near suture lines, or in sunken and therefore better protected places, one may usually discover it if present. Two kinds of surface are to be found in this and allied genera: One consists of a very fine network, representing the surface growth of the stereom constituting the plates (Pl. XXIV, fig. 11*a*), such as we find on the outer skin of the Recent crinoids; such a surface should be called smooth. In the other the stereom itself is elevated into more or less well-defined granules or small nodes, which by their confluence into straight or curved lines form distinct ridges; or it is excavated by pits and furrows, thus producing a rugosity wholly different from the simple meshes of the first kind (Pl. XXXII, fig. 11*f*). This rugosity varies somewhat in intensity, but it is doubtful if the degree of such ornamentation is sufficiently constant for use as a specific character; however, the presence or absence of surface markings is apparently constant, and furnishes the basis for one of the broadest groupings we have in this genus.

In the description of the species I make no attempt to give measurements, except to indicate the maximum or average size, and certain relative proportions which often constitute a useful guide and bring out the facts as to actual form better than ordinary descriptive terms. This practice is especially useful in the treatment of this and allied genera, by reason of the misleading appearance of the specimens due to flattening. In order to have data for comparison I usually take the width at the level of the upper secundibrach, the vertical height from the base to that level, and the diameter by calculation either from the circumference measured on free specimens, or computed from the width of the secundibrach at that point. The measurement is taken at the upper margin or apex of the plate mentioned, and to avoid tedious repetition this is not further stated in the description; thus if the data given is for a radial, or a non-axillary brachial, it means at the upper margin of that plate; if for an axillary, the height is taken at the apex. Also in this genus and others of this family for purpose of better comparison I measure the spread of the calyx from the top of the radial, instead of from the base or column facet as is usually done in those of other families.

The size of the crown varies considerably in the different species. *I. corbis* and *I. laevis* attain a large size, though small specimens are found, especially of the latter species, showing marked juvenile characters. *I. subangularis* is also a fair-sized species. *I. pyriformis* and *I. gotlandicus* are generally small.

The figures given show the average of the available specimens, and my experience with this genus is that in relative proportions individual specimens do not depart very widely from the mean. It is of little use to give elaborate measurements or proportions of separate plates, as they vary too much in the same specimen. In a general way we find that in a rapidly spreading species, like *I. corbis,* the brachials are proportionally shorter and wider than in an elongate, less expanded form like *I. subangularis.*

The ten species may be arranged as follows:

### THE SPECIES OF ICHTHYOCRINUS

#### *Silurian Species*

- I. Surface ornamented. Calyx without radial ridges.
  - Crown pyriform.
    - BB well-developed. IIBr usually 4 .............................. *I. pyriformis.*
  - Crown ovoid.
    - BB small, covered by column. IIBr 3 .............................. *I. gotlandicus.*
- II. Surface smooth.
  - Crown pyriform.
    - BB small, visible as triangles in lateral view.
      - Calyx rounded, with low radial ridges. IIBr 4 .............................. *I. laevis.*
  - Crown turbinate or conical. IIBr 4.
    - BB large, visible as pentagons.
      - Calyx angular, with strong radial ridges.
        - Base contracted to a truncate neck .............................. *I. subangularis.*
        - Base rounded or curving evenly with calyx wall .............................. *I. intermedius.*
    - BB small, visible as triangles.
      - Calyx narrowly elongate without radial ridges .............................. *I. conoideus.*
  - Crown ovoid.
    - BB small, covered by the column.
      - Calyx angular, with radial ridges. IIBr 3 .............................. *I. phillipsianus.*
      - Calyx rounded, with obscure radial ridges. IIBr 4 .............................. *I. corbis.*

#### *Devonian Species*

- Surface smooth. Calyx without radial ridges.
  - Crown pyriform.
    - BB small, covered by the column. IIBr 3 .............................. *I. devonicus.*
  - Crown ovoid.
    - BB unknown. IIBr 3 .............................. *I. bohemicus.*

## **Ichthyocrinus pyriformis** (Phillips)

*Plate XXXII, figs. 1-13*

*Cyathocrinites pyriformis* Phillips in Murchison, Silurian System, 1839, p. 672, pl. 17, fig. 6.

*Carpocrinus pyriformis,* Müller, 1843, p. 33.

*Cyathocrinus pyriformis,* Hall, Nat. Hist. New York, Pal. II, 1852, p. 196.—Quenstedt, Petrefaktenkunde Deutschlands, IV, 1876, p. 502.

*Ichthyocrinus pyriformis,* D'Orbigny, Prodr. Pal. Stratigraphique, I, 1849, p. 46.—Morris, Cat. Brit. Foss. 2nd Ed. 1854, p. 83.—M'Coy, British Palaeozoic Fossils, 1854, p. 54.—E. Billings, Canadian Nat. and Geol., I, 1856, p. 59.—Pictet, Traité Paléontologie, IV, p. 319.—Phillips in Murchison, Siluria, 3d Ed., 1859, p. 246 [*Ichthyocrinus* (*Cyathocrinites*) on plate] pl. 14, fig. 8.—Beyrich, Monatsber. Akad. Wiss. Berlin, 1871, p. 45 (Transl. in Ann. and Mag. Nat. Hist., (4) VII, p. 403.—Salter, Cat. Cambrian and Silurian Fossils, 1873, p. 126.—Angelin, Icon. Crin. Sueciae, 1878, p. 13, pl. 22, fig. 22 (not pl. 17, fig. 6 = *Clidochirus*).—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 35.—Quenstedt, Petrefaktenkunde, 1885, p. 947, pl. 76, fig. 1.—Bather, Ann. and Mag. Nat. Hist., (6) IX, Mar. 1892, p. 206; (*piriformis*) Rep. Museums Assoc. for 1891 [1892], p. 92; Treatise on Zoology (Lankester) pt. 3, 1900, p. 188, fig. 108.—Springer, Jour. Geology, XIV, 1906, p. 477.

*Curious Fossil,* Ellis, Philosophical Transactions, LII, 1762, p. 361, pl. 13, Fig. B.

*Encrinus,* Whitehurst, An Enquiry into the Origin, State and Formation of the Earth, 1786, p. 235, pl. 7, fig. 1 (after Ellis).

*Fig Pentacrinite* Parkinson, Organic Remains of a Former World, 1808, pp. 258, 270, 271, 274, pl. 19, fig. 2 (after Ellis).

*Cyathocrinites tuberculatus* Miller (in part), Nat. Hist. Crinoidea, 1821, p. 88, fig. 2.

*Pentacrinus tuberculatus,* Quenstedt, Petrefaktenkunde Deutschlands, IV, 1876, p. 193, pl. 97, fig. 7.

*Ichthyocrinus laevis,* Angelin (in part) 1878, p. 13, pl. 91, figs. 17*a-c* (not pl. 22, figs. 20, 21 = *I. gotlandicus*).

A rather small species. Crown elongate, pyriform, with truncate base; expanding gradually, with spread of calyx from RR to upper IIBr of 1 to 4; height to width at that level, about 1 to 1.3; greatest width, about IIIBr$_3$. Side outline of calyx generally curving from concave below to convex; cross-section subcircular; median radial ridges obscure or absent. Crown of maximum specimen, 42 mm. high by 26 mm. wide at IVBr; but the average size of the specimens is much less—about 22 by 18 mm.; average width of base, 4 mm. Surface ornamented with small raised granules, often confluent and forming ridges or wrinkles parallel to margin of plates.

IBB of moderate size, covered by column. BB touching column, appearing in pentagonal outline, and usually well developed, but not large or completely exposed. Brachials somewhat rounded transversely, lower ones averaging twice as wide as high, proportionally wider above. IIBr generally 4, sometimes 3; IIIBr, 5 to 9, with one or two more bifurcations visible. Column expanding rapidly at the calyx to a diameter equal to that of the base.

This species resembles *I. laevis* more closely than any other, and Hall[1] considered them identical; while Angelin[2] referred a Gotland specimen of *pyriformis* to the latter species. The original description, though meager, throws some light upon its specific relations. Phillips, whose intuitive judgment of characters was always sagacious, was struck by the essential peculiarities of the form, and while describing it under *Cyathocrinus* stated that it ought probably to constitute a new genus; and he called attention to the great width, general equality, and lateral union of the plates as constituting easy characters—a generic definition fully as good as Conrad's. He gave however a very good figure (Silurian System, pl. 17, fig. 6), which affords a clear idea of the general form and proportions; and this, added to one more item mentioned in his brief description, enables us to recognize his species without any doubt. That is: "the surface is marked by a faint, irregular ornamentation, not unlike *Cyathocrinus tuberculatus.*"

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[1] Nat. Hist. New York, Geol. Fourth District, 1843, p. 112; *idem.,* Palaeontology, vol. 2, 1852, p. 196.

[2] Icon. Crin. Suec., 1878, p. 13.

M'Coy in 1854 referred the species to Conrad's genus, and gave a revised generic description, in which some important additional characters are pointed out—notably the absence of interradial plates. He also redescribed the species, giving a correct account of the column, but otherwise furnishing no new information. Most of his lengthy description is devoted to detailed measurements of various plates and "fingers," which unless given in the form of relative proportions amount to nothing more than the description of parts of a particular specimen.

Angelin identified the species among the Swedish forms, with good reason as to one of the specimens he figured (Icon. Crin. Suec., pl. 22, fig. 22), but not as to the other (*ibid.*, pl. 17, fig. 6) which is a fine example of his genus *Clidochirus.*

I have copied Phillips's original figure (Pl. XXXII, fig. 1), and along with it I have given figures, both natural size and enlarged, of a specimen in my collection from the same locality which in size and form is almost a counterpart of the type (*ibid.*, figs. 2*a, b, c*). An enlarged figure of one plate of this specimen (fig. 2*d*) shows the character of the ornamentation found on the English specimens. Several other specimens in my own collection and in the British Museum, from the typical locality at Dudley, England, and having the characteristic ornamentation (which scarcely appears in a drawing of natural size), show the small variation in form that is found. The resultant of all these taken together is an elongate, pyriform crown, in its proportions quite similar to that of *I. laevis,* but correspondingly different from the broadly spreading ovoid crown of *I. corbis* and *I. gotlandicus.* It is generally a more delicate form than *I. laevis,* the one large specimen from Gotland being very much larger than any of the others. Besides this the surface ornament clearly differentiates the two species.

In addition to several views of Angelin's plate 22, figure 22, erroneous in showing projecting IBB like *Clidochirus* (see Pl. XXXII, figs. 9*a-e* herein), I have figured on the same plate three other specimens of this species from Gotland with structural details still further illustrating the surface characters. Of these figures 11*a-g* are from Angelin's plate 9, figure 17, referred by him to *I. laevis,* and figures 13*a, b* are from a specimen of unusual size, much larger than the average of the English specimens. In all these it will be seen that the base is quite uniform, and altogether different in its development from that of *I. gotlandicus.* They, and others which I have examined in English collections, have quite generally four secundibrachs all around, with occasional exceptions in some rays, mostly by way of increase in number. I have therefore been somewhat puzzled over one of my specimens from Dudley, which has only three secundibrachs in most of the rami, but has the pyriform figure, well developed infrabasals, and fairly large basals of this species (Pl. XXXII, fig. 7*a*). It seems to be a variant in the direction of *I. gotlandicus,* and this is confirmed by the measured dimensions which give a proportion of height to width of 1 to 1.5.

The specimen figured by John Eills[1] in 1762, and copied by Parkinson,[2] may perhaps have been of this species. The figure is probably enlarged, although no mention is made of this in the text, and the drawing of the basal parts of the fossil is uncertain. The locality is given as Pyrton-Passage in Gloucestershire, where strata equivalent to the Wenlock are exposed.

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[1] Philosophical Trans. Roy. Soc. London, vol. 52, pl. 13, Fig. B.

[2] Organic Remains of a Former World, vol. 2, 1808, pl. 19, fig. 2 (reversed in copying). Also by Quenstedt as *Pentacrinus tuberculatus,* Petref. Deutschl., 1876, taf. 97, fig. 7.

*Types.* According to Murchison (Silurian System, p. 702) Phillips's figure and description were made from a specimen belonging to Mrs. Downing of Dudley, England, but its present whereabouts is unknown. Of the others figured on Plate XXXII, figures 4, 5, 6, 8 are in the British Museum; 9, 10, 11, 12 and 13 in the Riks Museum, Stockholm; and 2, 3, 7 in the author's collection.

*Horizon and locality.* Silurian, Wenlock Group. Chiefly at or near Dudley, England; Wisby, Dalham, Faro, and Follingbo (horizon *f*), Island of Gotland.

### **Ichthyocrinus gotlandicus** Wachsmuth and Springer

*Plate XXXV, figs. 1-16*

*Ichthyocrinus gotlandicus* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 34.—Springer, Jour. Geology, XIV, 1906, pl. 6, fig. 6.

*Ichthyocrinus laevis,* Angelin (in part), Icon. Crin. Sueciae, 1878, p. 13, pl. 22, figs. 20, 21, not pl. 9, figs. 17, 17*a-c*.

A small species. Crown ovoid to low pyriform, with truncate base; expanding rapidly from base beyond IIBr, the spread of calyx from RR to upper IIBr being 1 to 4; height to width at same level, about 1 to 1.6. Side outline of calyx curving from concave to convex; no radial ridges; cross-section circular. Surface ornamented with small raised pustules. Plates but little imbricated. Maximum crown, about 25 mm. high by 17 mm. wide at upper IIIBr; a larger fragment, 13 by 20 mm. at upper IIBr; average width of base, about 4.5 mm.

IBB very small, usually atrophied or entirely wanting. BB small, restricted to the column facet, or visible in side view only as mere points. RR and RA touching the column, RA usually entirely covered by it. IIBr generally 3; IIIBr 4 to 7. Average height to width of brachials above IBr, about 1 to 3. Column unknown below proximal columnals, which are as wide as the base.

In his Iconographia Crinoideorum Sueciae, Angelin figured two specimens from Gotland which he referred to *Ichthyocrinus laevis* of Conrad and Hall (*op. cit.,* pl. 9, figs. 17*a-c;* pl. 22, figs. 20, 21). Wachsmuth and Springer[1] disagreed with this identification, holding the Swedish specimens to be distinct from the New York species; and proposed for them the name *I. gotlandicus* upon the grounds stated. A careful examination of Angelin's specimens, together with several others since discovered, confirms their separation from the American form; but it also raises a rather close question as to what should be called *I. gotlandicus,* owing to the fact that the two specimens figured by Angelin and included in Wachsmuth and Springer's reference do not themselves belong to the same species. Our diagnosis of the species must be gathered from the following paragraph in the Revision, p. 34:

> The European form is pear-shaped instead of ovoid, the plates ornamented, but without any surface angularity, and with nearly straight sutures; while the New York specimens have plates with smooth but angular surface, and very distinct waving sutures.

As to the general form we were misled by the figures of Conrad and Hall, which as elsewhere explained appear ovoid merely because made from flattened specimens, whereas *I. laevis* in its undistorted condition is pyriform. Furthermore, only one of Angelin's specimens (Icon. Crin. Suec., pl. 9, fig. 17) is pyriform, the other being a low ovoid (see my Pl. XXXV, figs. 1*a, b*). The distinction based upon the sutures must also be abandoned, because we have since learned that all sutures in this genus are more or less sinuous at the outer surface and straight underneath, so that this character is a mere matter of preservation. Angelin's figures of his specimens were not accurate as to this; both of them show waving sutures in many places, as will be seen by comparison of the new figures now herein given from the careful drawings of Liljevall (Pls. XXXII, fig. 11*a*; XXXV, figs. 1*a*, *b*). As to surface angularity produced by median ridges following the radial lines, the first of these figures shows it to a slight extent, while the last does not. The remaining part of the observation was well founded and correct.

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[1] Revision of the Palaeocrinoidea, pt. 1, 1879, p. 34.

The result of the comparison of Wachsmuth and Springer's specific characters with the facts observed in the two specimens is therefore as follows (the reference being to my figures); (1) ornamented surface, present in both; (2) pear-shaped form, in Plate XXXII, figure 11 but not in the other; (3) surface angularity, in Plate XXXII, figure 11 not in the other; (4) straight sutures, in neither. Thus the one character common to both is the ornamented surface, and this applies equally well to *I. pyriformis.* Upon the second and third characters Plate XXXII, figure 11 agrees with that species, and for other reasons as well must be referred to it. This leaves only Plate XXXV, figures 1*a*, *b*, which as to the second and fourth characters stated by the authors does not agree with the diagnosis of *I. gotlandicus.* Nevertheless, as the general form is not wholly constant and cannot be regarded as a predominant character, it seems to me that we are at liberty to select such of the Swedish forms as are ornamented and without surface angularity, and then limit the species by such other characters as we have found to be important and can define by means of later observations.

As the ornamented surface is also shared by *I. pyriformis* we must look for characters differentiating that species, and when by this means *I. pyriformis* is detached, that which is left may be taken as *I. gotlandicus.* Such a character may be found in the development of the basals, bringing Plate XXXII, figure 11 under *I. pyriformis* on account of their large size, aided by the presence of four IIBr as against three. There will thus remain the Swedish specimens which have the basals very small, visible if at all in a side view only as mere points, and usually three IIBr; with these characters Plate XXXV, figure 1*a*, *b* alone out of Angelin's specimens agrees, and it may therefore be taken as the type of a very well-defined species, of which we have now a number of other characteristic specimens from Gotland. Thus it results that of Angelin's figures under the name *Ichthyocrinus laevis,* his plate 9, figures 17*a*-*c*=*I. pyriformis* (Pl. XXXII, figs. 11*a*-*g* herein); and his plate 22, figures 20, 21=*I. gotlandicus* (Pl. XXXV, figs. 1*a*, *b*, herein).

Mr. Liljevall has drawn for me all the specimens that are known at Stockholm, including two views of Angelin's plate 22, figures 20, 21 (Pl. XXXV, figs. 1*a*, *b* herein), and the beautiful enlarged figure of a fragment (fig. 16) showing the manner in which the distal ends of the arms are coiled, proving that the arms were much longer, and afforded more food-gathering surface, than appears from the usual condition of the specimens.

The crown is a low, broadly swelling ovoid, with sides strongly convex, except for a very short reverse curve in some specimens just above the base. The average of seven Gotland specimens gives a proportion of height to width of 1 to 1.6 at the upper IIBr, which is about that of *I. corbis;* but it is in marked contrast to the form of *I. pyriformis,* where the same dimensions are as 1 to 1.2. All these specimens have also quite uniformly three secundibrachs, as contrasted with the usual four in the Swedish and English specimens of *I. pyriformis.*

It is now most interesting to observe in the six Swedish specimens of which we have the basal view (Pl. XXXV, figs. 2-6, 15), how the peculiar construction of the base correlates with these two characters and differs from that of nearly all other species. The basals are very small, occupying little over half the space covered by the top stem ossicle; only occasionally does the narrow tongue of one of them reach to the outer surface so as to be visible as a mere point. The radials and radianal all come down to the stem and rest upon it. The infrabasals have completely disappeared, and in the place they once occupied there is now only an open space, larger than the lumen of the stem, but representing the axial canal of the calyx where it opens out into the chambered organ. The large size of this opening negatives the idea that the loss of the IBB was due to their adhering to, or fusing with, the stem, as in *Forbesiocrinus* and some other genera of this group. If it were so, the axial canal should remain of the normal size.

The space thus left by the disappearance of the infrabasals is of course radial in position, as they were, and it coincides with the usual orientation of the stem canal in pseudo-monocyclic or crypto-dicyclic crinoids such as *Isocrinus*. A similar condition occurs in *Cleistocrinus, Euryocrinus* and *Amphicrinus,* where the IBB are also wholly or partially resorbed.

Among the specimens figured is the one mentioned by Angelin on p. 13 of the Iconographia under *I. pyriformis* as having been deposited by Dr. Linnarsson in the Geological Museum at Stockholm (Pl. XXXV, figs. 15*a-c*), which appears at first glance to be a departure from the characteristic form of the species in the direction of *I. pyriformis;* yet the measurement of dimensions at the upper IIBr gives nearly the average proportion for the species, 1 to 1.5, while the base tells the story exactly (fig. 15*c*).

*Types.* The original of Angelin's pl. 22, figs. 20, 21, must be regarded as the type, and the other Swedish specimens figured herein, except Plate XXXV, figure 15, as cotypes. All are in the Riks Museum at Stockholm.

*Horizon and locality.* Silurian, Wenlock Group, horizons *d* and *f;* Gotland, Sweden.

### **Ichthyocrinus laevis** Conrad

*Plate XXXIII, figs. 1-13*

*Ichthyocrinus laevis* Conrad, Jour. Acad. Nat. Sci. Philadelphia, VIII, 1842, p. 279, pl. 15, fig. 16.—D'Orbigny, Prodr. Pal. Stratigraphique, I, 1849, p. 46.—Hall, Nat. Hist. New York, Pal. II, 1852, p. 195, pl. 43, figs. 2*a-p*.—E. Billings, Canadian Nat. and Geol., I, Feb. 1856, p. 59, pl. frontispiece, fig. 4.—Pictet, Traité Paleontologie, IV, 1857, p. 319, pl. 100, figs. 17*a, b*.—Beyrich, Monatsber, Akad. Wiss. Berlin, Feb., 1871, p. 45 (Transl. in Ann. and Mag. Nat. Hist., (4) VII, p. 403).—Quenstedt, Petrefaktenkunde Deutschlands, IV, 1876, p. 515; Handbuch Petrefaktenkunde, 1885, p. 947.—Von Zittel, Handb. Pal. 1879, p. 356, fig. 243; Grundzüge Palaeontologie, 1895, p. 138, fig. 270; 1910, p. 165, fig. 300.—Miller, N. A. Geol. and Palaeontology, 1889, p. 256, fig. 344.—Zittel-Eastman, Textbook Paleontology, 1896, p. 164, fig. 270; 1913, p. 204, fig. 305.—Grabau, 1901, p. 159, fig. 54.—Springer, Jour. Geology, XIV, 1906, p. 477, pl. 6, fig. 1.

*Cyathocrinites pyriformis,* Hall, Nat. Hist. New York, Geol. Fourth District, 1843, p. 111, fig. 3, p. 112, tab. 17, fig. 2.

*Lecanocrinus simplex,* Hall, Nat. Hist. New York, 1852, Pal. II, p. 202, pl. 46, figs. 2*a-e*.

Not *Ichthyocrinus laevis,* Angelin, Icon. Crin. Sueciae, 1878, p. 13, pl. 22, figs. 20, 21 = *I. gotlandicus;* nor pl. 9, figs. 17, 17*a-e* = *I. pyriformis.*

Type of the genus.

Species variable, attaining a large size. Crown elongate pyriform, with truncate base; expanding gradually from base to about the upper IIIBr; height to width at upper IIBr, about 1 to 1.6; spread of calyx from RR to same level, about 1 to 4. Side outline of calyx concave below, becoming convex upward, cross-section about circular; sometimes with slight projections at the radial ridges. Plates strongly imbricated; surface smooth. Maximum crown, 75 mm. high by 52 mm. wide at upper IIIBr; minimum, 14 by 11 mm.; average width of base, 6.5 mm.

IBB small, covered by column. BB small, not wholly exposed, visible as triangles beyond the column in side view; relatively larger in young specimens, which are also more elongate in general dimensions. Brachials obtusely rounded into a low median ridge, increasing in angularity upward, and well-marked in the upper ray divisions; median elevation of rays more apparent in flattened specimens, and scarcely observable at the lower part in rotund ones. IIBr generally 4, sometimes 3. Average height to width of IBr, about 1 to 2; of IIBr, about 1 to 3. Column long, proximally enlarged, expanding rapidly for a few ossicles to the diameter of the base; below this it is relatively small, diminishing in a medium-sized specimen from 5 mm. to 3 mm. continuing thus to near the distal end where it slightly enlarges. It is smooth, composed of nearly uniform columnals, and is at least 23 cm. in length.

Conrad's description of this species, like many of the earlier descriptions in this group, was short, but it contained one important point; it reads, " there is much resemblance in the markings of this fossil to the scales of a fish, whence the generic name is derived."[1] This feature, which he also gives as a generic character, is found in most of the species, but it is particularly well-marked in this, and distinguishes it from *I. subangularis* as usually found in the Waldron shales. It is illustrated on Plate XXXIII, figure 3*d*, where it will be seen that the plates do not actually overlap, but the upper transverse margin is rather abruptly raised just at the suture line, giving somewhat that appearance. In some specimens this projection is quite sharp and prominent, and can be easily felt by running the finger nail downward against the sharp little steps. In the English species *I. phillipsianus* this transverse elevation is considerably higher, and involves a larger portion of the plate (Pl. XXXVI, fig. 14*c*).

Conrad's figure (*op. cit.*, pl. 15, fig. 16) leaves no doubt that it represents the species found in the Niagaran shales at Lockport, New York, but if we did not have other specimens in similar condition for comparison it would be misleading in several particulars. It is made from a flattened specimen, and the sides appear as if convex almost from the stem. The base and small part of the stem shown are too small, doubtless because not perfectly cleaned from the matrix. In a normal specimen the base is fairly broad, and the side of the calyx expands upward with a slight inward or concave curve, which is soon reversed into a broad convex outline extending to the level where the arms are folded inward—the zone of greatest width being a little over half way up, and considerably above the level where the curve changes. This is well shown in such rounded specimens as Plate XXXIII, figures 3, 4. But with a flattened specimen the side outline is very different; the whole effect of the reversed curve is lost and the calyx appears convex from the base up, as in Conrad's figure. In order to show the result of such flattening I have given, along with the figures of several such specimens, their curved outlines obtained by calculating the diameter from accurate measurements at four zones (Pl. XXXIII, figs. 10*b*, 11*b*, 12*b*, 13*c*).

These figures show what a substantial uniformity there is in the contour of the specimens, however much altered by pressure. In young specimens the characteristic figure has not been fully attained; they are more ovoid, and also more elongate (figs. 5, 6). The specimens vary somewhat in the prominence of the median radial ridge in the lower part, where it is often quite obscure, especially on rotund specimens; but it is always distinct in the higher parts of the rays, where it becomes quite angular. The column is rather small for the size of the crown except at the calyx where it is flush with the base, and tapers very rapidly for a few thin columnals to little more than half that diameter; thence it continues with perfectly smooth, straight, slightly alternating columnals of uniform diameter until toward the distal end where it is somewhat enlarged. I have three specimens (obtained too late for figuring) in which the column is preserved to a distance of about 23 cm., where a branching root begins to appear.

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[1] Jour. Acad. Sci. Philadelphia, vol. 8, 1842, p. 279.

In average size, and the low, sharp imbrication of the plates, this species resembles *I. corbis;* but its radial ridges are stronger, basals larger, and it lacks the low, broad, convex figure of that species. Of all other species it most resembles *I. pyriformis,* with which Hall identified it; but the absence of surface ornament and the stronger imbrication of the plates in this will readily differentiate the two.

Angelin identified a Gotland form as *I. laevis* (Icon. Crin. Suec., pl. 9, fig. 17), which is clearly distinct by reason of its ornamental surface, smaller basals and other characters, as has been more fully shown under *I. pyriformis* to which it belongs, and in the discussion of *I. gotlandicus.*

In the year following Conrad's publication of his species and genus, Hall in the Geology of the Fourth District of New York, p. 111, figure 3, published a figure of a flattened specimen with part of the stem attached, which he described on page 112 under the name of *Cyathocrinites pyriformis* (*Ichthyocrinus laevis*), declaring that he had "no doubt of the identity of the fossils figured by Mr. Murchison and Mr. Conrad." Nine years later, in the Palaeontology of New York, vol. 2, p. 195, he redescribed the genus and species at considerable length under Conrad's name, stating at the same time that "the genus is known only in a single species," and adhering to his former opinion, stated that "this is probably the same species figured by Murchison as *Cyathocrinus pyriformis,* and is perhaps identical with figure 2 of Miller's *Cyathocrinus tuberculatus.*" He added: "The structure, however, shows conclusively that it should constitute a distinct genus. The remarkable character of an undeveloped tripetaloid base assimilates it with the crinoids having this structure, or three pelvic plates succeeded by five in the second series." He gave the structure of the calyx from the five pelvic plates up, and laid stress upon the tapering base and slender round column as distinguishing characters; but he did not mention the imbrication of the plates, which was beautifully shown in some of his own specimens. He did, however, well describe the structure by which the plates of abutting rays alternate with each other and produce the interlocking so characteristic of the genus.

Hall illustrated the species very thoroughly with figures of three specimens, accompanied by elaborate diagrams of structural details. Among them are enlarged views showing the three "undeveloped" plates (infrabasals) and five "pelvic plates" (basals) (*op. cit.,* pl. 43, figs. *2a-p*). I have given new figures of two of Hall's specimens, *2b* and *2c,* carefully drawn from the original specimens (Pl. XXXIII, figs. 2, 5*a*). By comparing my figure 2 with Hall's figure *2b,* it will be seen that the stem is not so slender as his figure shows; and if we further compare the figures of my three specimens with stems attached to a greater length than his, it will be evident that the stem, on whose thinness Hall and others following him have laid particular stress, is by no means so thin as his and Conrad's figures would indicate. And I have no doubt that in these and Hall's figure *2a,* also showing a very thin stem, the column was not freed from the matrix to its full diameter. The form of the stem in this species is simply that characteristic of the genus, and is of the type which extends through almost the entire group; that is, large at the junction with the base and composed of very thin columnals, tapering gradually for a short distance and then becoming cylindrical, with alternating short and long columnals.

Billings[1] in 1856 published a description of this species, which was taken from Hall, and gave no additional information. Hall's figure *2a,* evidently made from the same specimen as his first figure in the Geology of the Fourth District, 1843, p. 111, figure 3, has been copied by S. A. Miller; his figure *2b* by Von Zittel and others. Pictet's plate 100, figure 17*a* is a fairly good copy of it, and his *17b* a reconstruction of *17a* with arms closed and a stem added from Hall's figure *2a*. It is by the figure *2b* that the species has been known to paleontologists the world over, rather than by Conrad's. It is therefore particularly unfortunate that neither the type specimen of Conrad, nor the original of this much-quoted and classic figure by Hall, can now be found after the most careful personal search and extensive inquiry.

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[1] Canadian Naturalist and Geologist, vol. 1, p. 59.

The latter specimen was supposed to be in the American Museum of Natural History, where the originals of Hall's *2b* and *2c* are, together with the beautiful specimen now first figured by me (Pl. XXXIII, figs. 3*a*, *b*), all being from the original collection of Professor Hall. It is so stated in Whitfield and Hovey's List of Types,[1] but an examination of all the specimens of this species in the collection has failed to discover it. Hall at the end of his description (Palaeontology of New York, vol. 2, p. 196) credits all the specimens figured by him to the State collection and the collection of Col. Jewett. This specimen cannot be found at Albany, and is not claimed in the List of Types published by the State Museum[2] in 1903. Learning that a part of Col. Jewett's collection was acquired by Cornell University, I also sought for it there, equally without success.

No better fortune has attended the search for Conrad's type. It was supposed to be in the collection of the Philadelphia Academy of Natural Science, and may in fact be there buried out of sight, but neither the specimen nor any trace or record of it can be found. As some of the specimens used by Conrad in various descriptions are known to have been obtained from Hall, it was thought this one might be in some of the collections formerly controlled by him; but a careful search both at Albany and New York has failed to afford any information. There still remained a second large private collection of Professor Hall additional to that acquired by the American Museum, stored at Albany until recently, when it was purchased by the University of Chicago. Inspection of this material, thanks to the courtesy of Dr. Weller, resulted in the discovery of some plaster casts from the original of the figure of 1843, such as Hall was accustomed to preserve from specimens borrowed from private owners.

As this information was not obtained until after the plates for this work had been prepared, I must refer again to Hall's two figures of the specimen above cited in order to point out some inaccuracies which apparently contradict the specific diagnosis. The earlier figure is a rather rough sketch showing the general form but not the definite arrangement of plates. That of 1852 in the Palaeontology of New York, volume 2, plate 43, figure *2a*, is an artistic picture but faulty as to essential details; it shows five secundibrachs in most of the rays, and all the arms uniformly simple beyond the third bifurcation, whereas in the cast the secundibrachs are the usual four, and there is a fourth bifurcation in some of the rami. The cast also shows very clearly the presence of the radianal at the base of the right posterior ray, while in the drawing that ray is not different from the others.

I have endeavored to give as complete a representation as possible of the typical species, in all stages. The specimen figured by me on Plate XXXIII, figures 3*a*, *b*, now in the American Museum of Natural History, is the finest one of this or any other species of the genus that I have seen. Except for a little foreshortening and lateral bending of the infolded arms, it is absolutely rotund and perfect. The original of figure 13 on the same plate is the largest known specimen; it is from Grimsby, Ontario, and belongs to the magnificent collection of Silurian and Devonian fossils brought together by Sir Edmund Walker of Toronto, Canada, and now through his liberality a part of the Museum of the University of Toronto. It is a very mature specimen, with six bifurcations in some rays; and owing to age and wear the sinuous sutures have almost disappeared from the lower part. In striking contrast to this are figures 7 and 8, which are interesting examples of the young stage; the juvenile characters are strongly expressed by the shortness of the rays, which have but a single bifurcation; the larger base and consequent ovoid instead of pyriform crown; and by the stem with its long non-alternating columnals. Upon such a specimen Hall proposed his *Lecanocrinus simplex*. None of the specimens show any trace of surface ornamentation in the sense mentioned in the generic description.

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[1] Bull. Amer. Mus. Nat. Hist., Vol. II, pt. 2, 1899, p. 92.

[2] Bull. 65 New York State Museum, p. 71.

*Types.* The facts as to these are given above. The originals of Hall's figures *2b* and *2c*, Pal. New York, plate 43, are in the American Museum of Natural History, New York. Except where otherwise stated the remaining specimens used in the illustrations are in my own collection. Those with stems attached were collected many years ago by Dr. Ringueberg of Lockport, and passed into my hands with the rest of his rare collection of the crinoids of that region.

*Horizon and locality.* Silurian, the species is confined to the Niagaran group of western New York and Canada, and has only been found in the Rochester shales. All the known specimens have come from Lockport, New York and Grimsby, Canada.

### **Ichthyocrinus subangularis** Hall

*Plate XXXIV, figs. 1-10*

*Ichthyocrinus subangularis* Hall, Adv. Abstract Trans. Albany Inst., 1863, p. 7; Trans. Albany Inst., IV, 1864, p. 201; Adv. Pub. 18th Rep. New York St. Cab. Nat. Hist., 1865, p. 21, pl. 2, figs. 15, 16; *ibid.*, 20th Rep., Doc. Ed., 1867, pp. 325, 384, pl. 11, figs. 15, 16; Rev. Ed., 1870, pp. 367, 429, pl. 11, figs. 15, 16; *ibid.*, 28th Rep., 1879, p. 137, pl. 16, figs. 11, 12, 13; 11th Rep. St. Geol. and Nat. Hist. Indiana, 1882, p. 268, pl. 15, figs. 12, 13; pl. 16, figs. 11-13.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 35.—Miller, Jour. Cin. Soc. Nat. Hist., IV, 1881, p. 175; sep. p. 10; N. A. Geol. and Palaeontology, 1889, p. 256.—Weller, Bull. 4, Chicago Acad. Sci. 1900, I, p. 146, pl. 15, figs. 3-5.—Springer, Jour. Geology, XIV, 1906, p. 477, pl. 6, fig. 2.

A large species. Crown elongate, narrowly turbinate or obconic below the widest part, contracting into a distinct neck at the base next to column facet; subangular from radials up owing to median elevation of the brachial series; base truncate; height to width at upper IIBr, about 1 to 1.1; spread of calyx from RR to same level, about 1 to 2.4. Side outline of calyx slightly convex; cross-section at IIBr subpentangular. Plates but little imbricated; surface smooth. Lower calyx plates very thin. Maximum crown, 70 mm. high to IVBr by 43 mm. wide at about IIIBr$_4$, the arms not being complete; base of average specimen, 7 mm.; complete crown of smaller size, 31 by 18 mm.; width of base, 5 mm.

IBB small, covered by the column. BB larger than in any other species, well exposed in pentagonal outline, but lower angles concealed by the column; salient angles rather long. Brachials with obtusely angular longitudinal median ridge, prominent in the first and second series, diminishing upward. IIBr usually 4. Average height to width of IBr, about 1 to 1.8; of IIBr, 1 to 2.4. IIIBr 6 to 10, with another bifurcation visible. Column unknown.

The history of this species and its relations to *I. corbis* are more particularly set forth under that species. It is a rare fossil at its typical locality, Waldron, Indiana, where it occurs in the Waldron shales of the Niagaran group. I have referred to it specimens from the Racine dolomite beds at Chicago, and from the Rochester shales at Lockport, New York. It is possible that some of these belong to distinct species, but upon any diagnostic characters visible in the fossils as preserved I am unable to separate them. The largest specimens are from Waldron, but none have been found there with the arms preserved beyond the IVBr.

The calyx wall is very thin in its lowest part, being in the largest specimen less than one millimeter in thickness from the first primibrach to the tertibrachs, but increasing somewhat above that; and there is to be observed a slight tendency to the lateral distortion near the base so frequent in *I. corbis.*

The species was originally described from the specimen which was afterward figured in the 20th Report of the New York State Cabinet of Natural History, plate 11, figure 16, again in the 28th Report, plate 16, figure 13, and which I have refigured (Pl. XXXIV, fig. 1). It is not exactly characteristic of the form of the crown as now known from other specimens, being more convex and less elongate and angular—probably due to vertical compression. Hall afterward in the 11th Report of the Indiana Geological Survey, plate 15, figure 13, figured a large specimen with the ray divisions preserved to a greater length than in any other Waldron specimen known; this I have also refigured (Pl. XXXIV, fig. 6). These, together with my own specimens which show the base and undistorted form of the calyx somewhat better (figs. 2, 3, 4, 5), give the best obtainable representation of the species.

I have also refigured on the same plate (fig. 7) the specimen from Bridgeport, Illinois, figured by Hall in the 20th Report, plate 11, figure 15, which is discussed under *I. corbis.* This specimen with the external surface preserved is strikingly similar to the present species except in its imperfect base, and it is difficult to conceive how the internal cast of its calyx could in any way have resembled the singularly distorted figure of *I. corbis,* so common in the same formation. The improbability of such a resemblance is emphasized by the fact that other Bridgeport specimens in my collection consisting of casts like those of *I. corbis* are in proportions, size of plates, contour at the base and angular ridges, excellent examples of *I. subangularis* as found at Waldron (Pl. XXXIV, fig. 8).

*Types.* There is some conflict in the claims to possession of the type specimens in the Lists of Types issued respectively by the American Museum of Natural History at New York, and the New York State Museum at Albany. Having through the courtesy of the authorities of those Museums had the opportunity to carefully examine all the actual and supposed types, I am able to state the facts with certainty: The type specimen, on which the species was originally described in the Transactions of the Albany Institute, volume 4, p. 201, is the one figured in the 20th Regent's Report, plate 11, figure 16, and refigured in the 28th Report, plate 16, figure 13. This specimen, and the originals of Hall's figures in the 20th Report, plate 11, figure 15 (the Bridgeport specimen), and in the 28th Report, plate 16, figures 11 and 12, are in the American Museum. The originals of the 11th Indiana Report, plate 15, figures 12 and 13, are in the New York State Museum. The figures on plate 16 of the 28th Report were republished under the same numbers in the 11th Indiana Report, being printed from the same stone.

*Horizon and locality.* Silurian, Waldron shales at Waldron, Indiana; Racine dolomite at Chicago (Bridgeport), Illinois; Rochester shales, Lockport, New York.

### **Ichthyocrinus intermedius** Angelin

*Plate XXXIV, figs. 11-14*

*Ichthyocrinus intermedius* Angelin, Icon. Crin. Sueciae, 1878, p. 13, pl. 17, fig. 7.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 34.—Springer, Jour. Geology, XIV, 1906, pl. 6, fig. 5.

Angelin described under this name a complete crown from Faro, in Gotland, which has the chief essential characters of the American species, *subangularis,* differing however in having the base rounded or curving evenly with the calyx wall, instead of being contracted into a distinct neck sharply truncate below. His figure was poor, and I have therefore given new and accurate drawings of the original specimen in several views (Pl. XXXIV, figs. 11*a-f*). This specimen is peculiar in having an extra primibrach in the left anterior as well as the right posterior ray—the only case of the kind I have seen in *Ichthyocrinus*. There are also figured two other fragments showing the base (figs. 12, 13), both in the Riks Museum at Stockholm. In general proportions these specimens closely agree with those from America, and the radial ridges are similarly conspicuous. I have a single specimen from the approximately equivalent Wenlock formation at Dudley, England (fig. 14), which I have referred to the same species, though it is perhaps not a very characteristic form; it has about the same proportions, rather obscure radial ridges, and a perfectly smooth surface; but the basals are not quite so well developed as in the Swedish specimens; and it does not agree with any other species, differing wholly in the surface from *I. pyriformis* under which name it was labeled.

*Types.* The Swedish specimens are in the Riks Museum, Stockholm; that of figure 14 is in the author's collection.

*Horizon and locality.* Silurian, Wenlock Group; Gotland, and England.

## **Ichthyocrinus conoideus** Ringueberg

*Plate XXXVI, figs. 8-12*

*Ichthyocrinus conoideus* Ringueberg, Annals New York Acad. Sci., V, 1890, p. 305, pl. 3, fig. 5.

A rather small species. Crown narrow, elongate conical, with straight sides to level of $IIBr_3$ where height to width is 1.1 to 1, expanding very greatly above that; spread of calyx from RR to IAx, about 1 to 1.2; to $IIBr_3$, about 1 to 3; base truncate; cross-section circular. Surface smooth, without radial angularity, and plates not imbricated in lower part. Largest specimen, 22 mm. high by 20 mm. wide at top of $IIBr_3$.

IBB small. Basals small, exposed only as triangles in side view. Brachials without longitudinal elevation. IIBr 4. Superior parts and column unknown.

This species occurs at Lockport, New York, in the Gasport limestone, a horizon above that of *I. laevis.* Ringueberg's original material was imperfect, he having but three fragmentary specimens in all, and only one of these has the plates preserved as high as $IIBr_3$. I have recently obtained about a dozen additional specimens from the same beds, none of them perfect, but some preserving the plates to the fourth IIIBr; they show the extreme narrowness of the lower calyx as seen in Plate XXXVI, figures 9 and 12*a,* a character not so evident in Ringueberg's figured type (fig. 8*a*) as in the other specimens used by him; figure 11 shows the contour of the crown to what is probably the widest zone. Most of the specimens have the base very well preserved, and they agree perfectly in the small size of the basals, thus distinguishing the species at once from *I. subangularis* which it nearest resembles in figure. The brachials throughout are relatively very high, indicating an extremely elongate crown; yet specimens with the highest brachials (*e. g.,* figs. 12*a, b*) have the small basals almost covered by the column, and visible only as small triangles in a side view. They all lack the strong radial ridges and general angularity of *I. subangularis,* the strongly curving side outline of *I. laevis,* and the well-developed basals of both these species.

*Type.* This and the other specimens figured are in the author's collection.

*Horizon and locality.* Silurian, Gasport limestone of the Niagaran; Lockport, New York.

### **Ichthyocrinus phillipsianus** n. sp.

*Plate XXXVI, figs. 13-14*

A large species. Crown ovoid, with rounded base curving from the column, expanding rapidly; spread of calyx from RR to $IIBr_4$, 1 to 3.2; height to width at that level, about 1 to 1.6; widest at the lower IVBr. Side outline convex, cross-section at IIBr decagonal; radial ridges prominent from RR up, rounded below and becoming angular upward, extending the full length of the crown. Surface smooth; plates strongly imbricated. Maximum crown, 41 mm. high by 33 mm. wide at IVBr; width of column facet, 5 mm.

IBB very small. BB small, covered by the column, and only visible in side view, if at all, as small points. Brachials longitudinally elevated into median ridges. IIBr 4; IIIBr 5 to 7 or 8, with two more bifurcations visible before infolding; height to width of brachials above IBr, about 1 to 3. Arms diminishing rapidly after third bifurcation and becoming very slender. Column unknown beyond the proximal columnals, which are as wide as the base of the calyx.

Among some specimens obtained from Dudley, England, some years ago, labeled *Ichthyocrinus pyriformis,* was one which always seemed to be out of place among the others; and upon the final close definition of the several species it appears that this specimen does not agree with any hitherto described. I have since obtained three fragments of the same form, and have seen in an English collection another specimen somewhat larger than mine. With this confirmatory evidence I propose a new species, dedicated to the memory of John Phillips, the author of the earliest species of the genus.

This species is of the general type of *I. corbis* in its ovoid figure, smooth surface and small basals, with the surface angularity of *I. subangularis* produced by the prominent radial ridges extending from the radials to the end of the visible rays. The infrabasals are not wholly resorbed as in *I. gotlandicus,* but they are very small. Part of the radials rest upon the stem, and the whole of the radianal is concealed by it; only the merest points of the basals, if any, appear at the exterior. On the principal specimen the short fragment of the stem was broken across very close to the calyx, and I ground off the thin adhering part of the upper ossicle so as to clearly show the plates of the base. Thus views are obtained with and without the stem attached (Pl. XXXVI, figs. 13*a, b*).

From another specimen preserving the upper part of the rays we obtain interesting details of the so-called imbricated structure of the plates, and of the extreme proportionate depth of the higher brachials (figs. 14*a-e*). The imbrication of the plates is very pronounced, and the transverse elevations show distinctly in a dorsal view; they are higher, broader, and in every way more conspicuous than in any other species.

This species wholly lacks the characteristic pear-shaped figure of *I. pyriformis,* and its ovoid contour, smooth surface, and small basals further essentially distinguish it from that species.

*Types.* In the author's collection.

*Horizon and locality.* Silurian, Wenlock Group; Dudley, England. The species has not been recognized in Gotland or America.

### **Ichthyocrinus corbis** Winchell and Marcy

*Plate XXXVI, figs. 1-7*

*Ichthyocrinus corbis* Winchell and Marcy, Mem. Boston Soc. Nat. Hist., I, 1865, pp. 89, 108.—Hall, 20th Rep. New York St. Cab. Nat. Hist., 1867, pp. 384, 391.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 34.—Miller, Jour. Cincinnati Soc. Nat. Hist., IV, 1881, p. 175, pl. 4, fig. 5; N. A. Geol. and Palaeontology, 1889, p. 256, fig. 343.—Weller, Bull. 4, Chicago Acad. Sci., I, 1900, p. 146.—Springer, Jour. Geology, XIV, 1906, p. 477.

A large species. Crown ovoid, without prominent surface angularity; expanding rapidly from base, with spread of calyx from RR to upper IIBr of about 1 to 2.4; average height to width at this zone, about 1 to 1.6. Side outline convex; cross-section circular. Surface smooth; plates of higher brachials somewhat imbricated. Maximum incomplete crown to about fourth bifurcation, 60 mm. high by 50 mm. wide; large specimen, 54 mm. high by 43 mm. wide at upper IIBr; small specimen, 13 by 18 mm.

IBB small, perhaps obsolete. BB small, probably not visible beyond the column. Lower brachials evenly curved, rarely with obscure median ridge, or becoming somewhat angular above. IIBr 4, IIIBr 6 to 8. Average height to width of brachials above IBr, about 1 to 3. Complete crown unknown, but in large specimens not infolding at the fourth bifurcation. Column unknown.

This species is chiefly known from internal natural casts which have been collected somewhat abundantly in the magnesian limestone of Niagaran age at Chicago. As usually found the plates have been destroyed by chemical action, leaving a limestone cast of the interior formed by the filling of the visceral cavity and replacement of the soft parts by the infiltrating matrix. On these casts the suture lines at the junction of the plates in specimens otherwise well preserved are sharply marked by thin, knife-like ridges. Even when not destroyed the test is softer than the matrix and rapidly disintegrates, leaving the impression of the interior as before. But few specimens have ever been found with any portion of the test preserved, and none with the calyx complete.

It is a remarkable fact that almost without exception these specimens are rotund, being but little flattened as is frequently the case with other species. This indicates that they were imbedded in a very soft, homogeneous and plastic matrix, which surrounded and supported them uniformly on all sides, replacing the soft parts before the pliant calyx became subjected to any pressure except from the gravity of its own viscera. We find, however, in by far the greater number of the specimens a peculiar distortion at the lower part of the calyx, where to the height of about the first IIBr it appears as if bent in on one side while the opposite is more than correspondingly ventricose, and the apex of the base points away from the vertical axis of the crown (Pl. XXXVI, fig. 3*a*). Among the few specimens found with any part of the plates *in situ* none have the base intact, so that we cannot be certain of the exterior form, although I have no doubt that it partook of the same distortion. The best one of these (figs. 6*a*, *b*) shows that while the calyx wall is quite thick and strongly arched toward the higher brachials, it becomes very thin in the lower part where the unsymmetric bending of the wall occurs.

When I first discovered the existence of the radianal on the convex side of a number of specimens like figures 2, 3, I thought the asymmetry might be due to the anal structures; but other specimens like 4, 5, with the radianal on the concave side, disposed of this theory, and I found that the distortion bore no fixed relation to the posterior side. It is not due to growth in that position, for that would require the crown to stand at an angle from the axis of the stem, which would not only be highly improbable with a large calyx supported uniformly at all sides by the surrounding water, but is negatived by the fact that careful measurement fails to show any modification such as this would produce in the shape and size of the plates, or differences in dimension between the concave and convex sides.

I am disposed to think the phenomenon is best explained by the conditions of fossilization, taken in connection with the peculiar construction of the test in this and similar species. In the upper part the walls are strong, built up of a great number of small but thick plates perfectly fitted together like the stones of an arch; this afforded considerable resistance to outside pressure in that part. Furthermore, it is characteristic of this genus and most others of the family to have the arms tightly infolded over the tegmen, which would still further strengthen the calyx there. In the lower part, as already stated, the calyx wall becomes extremely thin (not over one millimeter), and this along with the loose articulation of the plates among themselves rendered that part very pliant, yielding readily to pressure in any direction; just at the base the plates were necessarily thicker by reason of connection with the stem. Thus there were two zones of strong construction with a weaker one interposed.

The crown with its closely infolded arms being elongate and ovoid, on becoming detached from the stem tended to lie on its side in the soft ooze of the sea bottom into which it slowly sank and became imbedded. The weight of the visceral mass caused the lower side to settle at the zone of least resistance and the upper side to follow it, while the upper part of the crown, being of stronger construction, retained its shape. This would make the lower part of the calyx wall ventricose at the under side and concave at the upper, with the apex of the base pointing upward out of the line of the axis. There is a slight tendency to the same condition in *I. subangularis,* where in some specimens one ray is more protuberant near the base than the others. The calyx in that species, being much narrower, more elongate, and not having the ovoid shape that this has, yields but little and the distortion is not very marked.

While I have not given it as a character in the diagnosis, nevertheless this distortion is one of the most conspicuous features of the species as it has been usually found, which has been remarked by all observers, and by which it can be instantly recognized. In a lot of over one hundred and fifty specimens collected in early days by Sir William van Horne, and now in the University of Chicago, every one shows it in a greater or less degree. Some specimens, otherwise similar, have less distortion than the types illustrated, perhaps owing to their having exceptionally thicker walls, or more probably to their being imbedded nearly in a vertical position with the base up. In two such cases among my specimens the calyx is foreshortened so that the ratio of height to width is about 1 to 2. In other cases there is good reason for thinking they belong to different species.

This species has been the subject of considerable controversy. It was described with a diagram but without other illustration by Winchell and Marcy in 1865 in an extensive memoir upon the Fossils of the Niagaran limestone of Chicago,[1] with a very incorrect conception of the facts, due partly to the imperfection of their specimens, and partly to their lack of familiarity with the crinoids. They made the distinctive characters the " small size of the stem, large size of the basal plates . . . . the presence of two instead of three radials, and the perfectly straight transverse sutures,"—every one of which is wrong.

As to the number of radials, the authors said that the characters about the base are somewhat obscure, and they may have overlooked the real first radial; but this fact led them into an equally great error as to the basals, to which they assigned a form that is wholly imaginary and impossible. That which they called the very slender stem is the cast of the axial canal, probably enlarged by the resorption of the infrabasals; but their remark that it is " turned to one side in all our specimens " shows conclusively that they had before them the form so well known from those rocks with the peculiar distorted base, and leaves no doubt of the identity of the species which they were attempting to describe.

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[1] Mem. Boston Soc. Nat. Hist., Dec. 1865, p. 89.

Winchell and Marcy's paper was dated December 22, 1864, and was read before the Boston Society, January 15, 1865, and published under date December, 1865; but before it reached the press Hall published, as advance sheets of the 18th Report on the New York State Cabinet of Natural History, dated December 26, 1864, printed in January, 1865, a pamphlet entitled "Account of some new or little known species of Fossils from the Niagara Group,".[1] mainly devoted to fossils from the same rocks in Illinois and Wisconsin which had produced the species described by Winchell and Marcy. Many of these Hall pronounced identical with species described by him in 1863, and among them was an *Ichthyocrinus* which he referred to his *I. subangularis.* This provoked immediate hostilities, and a lively skirmish ensued characteristic of the wordy wars that raged at times among the American paleontologists of the last generation, growing out of the energy and enthusiasm with which they pursued their researches.

Winchell and Marcy added a supplementary note to their main paper (p. 108) vigorously defending their species, and as to *I. corbis* insisting on the absence of angularity and the straight suture lines as characters plainly distinguishing it from Hall's species, "not to speak of the supposed difference of basal structure."

To this Hall replied in the 20th Report of the New York State Cabinet for 1867, pp. 382-394, repelling the intimation of unfair practices, and maintaining his identification of the Bridgeport specimens with *I. subangularis.* He disclaimed the ability to found a species upon "supposed differences," and he properly stated that the straight suture lines are not a good character, because the double curvature seen on his species is an external feature, while the lines on the internal casts will necessarily be more direct. He gave a diagram from one of Professor Marcy's specimens showing correctly the basals and the missing radial, and insisted that the internal casts are subpentagonal. Winchell and Marcy did not continue the debate, and Hall's contention held the field until 1882, when S. A. Miller[2] espoused their cause, proposing to reinstate *I. corbis* on the strength of a specimen from Bridgeport (Chicago) preserving part of the plates. He found the main character for distinguishing the species to be in the "subradials" (basals), whose surface he declared to be elevated into a triangular pyramid. This peculiar specimen, now in the collection of the Chicago Academy of Science, is very imperfect, only parts of two rays being preserved; the basals have the triangular elevation mentioned by Miller, which may be their original shape or may be the result of secondary deposit of the calcite composing them. In any event it is not ***I. corbis,*** being an elongate form with straight sides, and relative height to width of 1 to 1.1—rather the proportions of *I. subangularis.*

In 1900, however, Weller[3] redescribing the Chicago specimens under the name *I. subangularis,* reaffirmed the identity of the two species, basing his opinion largely upon the specimen figured by Hall[4] from Bridgeport having the plates preserved. He rejected Miller's attempt to revive *I. corbis* on his Bridgeport specimen, which he declared to be a very small one, and he thought the protuberance of the basal plates a juvenile character.

Much of these differences of opinion might have been avoided by the consideration of one fact which has been overlooked in the various discussions, viz., that the specimens of *Ichthyocrinus* found in the Racine dolomite of the Illinois Niagaran are not necessarily all of the same species. No doubt there was here as elsewhere a modification of specific characters during the deposition of the strata of that epoch, or different species may have coexisted in the same area. We do not know that the various specimens described are all from the same bed, but there is good reason for believing that they all come from one limited locality. The original of Hall's figure 15 (20th Report, pl. 11), is said in the description to be from Bridgeport, Illinois. I have carefully examined this specimen, which is refigured herein (Pl. XXXIV, fig. 7). It is of the same material and preservation as the other Bridgeport specimens, and there is no authentic record of any *Ichthyocrinus* having been found elsewhere in the Chicago-Wisconsin area; so that I have no doubt it came from there. The relative dimensions and prominence of the radial ridges of this specimen clearly indicate its identity or close relationship with those of *I. subangularis* from the Niagaran shales at Waldron, Indiana; and the same characters show with equal force the distinctness of Hall's Bridgeport specimen from the other form common in that region.

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[1] Republished in the 20th Rep. N. Y. St. Cab. 1867, pp. 305-381.

[2] Jour. Cincinnati Soc. Nat. Hist., vol. 4, p. 175.

[3] Chicago Acad. Sci., Bull. 4, p. 147.

[4] 20th Report New York St. Cab. Nat. Hist., pl. 11, fig. 15.

In the way the collections have necessarily been made in the Chicago-Wisconsin region we have little knowledge of the exact beds from which the fossils have been derived. The dolomites of that area are held to be equivalent to the Lockport limestone, and to occupy a position intermediate between the Waldron and Rochester shales and the Brownsport limestone of the Tennessee area. We find from the Chicago region an assemblage of forms some of which are more or less restricted to particular horizons in the other regions, and also some not occurring elsewhere. Thus we have *Ampheristocrinus, Lyriocrinus, Macrostylocrinus* and *Periechocrinus,* which are mostly confined to the shales both at Waldron and Rochester; *Callicrinus, Lampterocrinus, Pycnosaccus, Zophocrinus,* which are found in the limestones of the other regions, but not in the Waldron or Rochester shales. And we also have genera like *Ichthyocrinus, Lecanocrinus, Eucalyptocrinus,* and *Myelodactylus,* which occur in both shales and limestones of the other regions. Hence the stratigraphy does not make for or against the probable occurrence of the same species in the two regions.

That the form of *Ichthyocrinus* occurring in the Niagaran of Northern Illinois represented by the well-known internal casts with usually distorted base, and to which Winchell and Marcy with however incorrect a description gave the name *I. corbis,* is an absolutely distinct species from that occurring in the Niagaran shales at Waldron and described by Hall as *I. subangularis,* may be conclusively demonstrated. They are in fact far more readily distinguished than some others which are separated by continental distances, for they fall under different divisions of the genus by some of its strongest characters. *I. corbis* is a rounded ovoid, with convex sides and circular cross-section, small basals, low and wide brachials having a very rapid increase in width upward, and a consequent broad spreading of the calyx within the first few ranges of plates. *I. subangularis* is elongate, irregular, with strongly prominent radial lines, and subangular cross-section; has large basals, relatively longer brachials, and a much less rapid spread of the calyx from the base up.

Actual measurement of a number of specimens is a more reliable guide in the matter of relative proportions than general impressions, and I have applied such a test in this case. The average of 15 representative specimens of *I. corbis* of all sizes, and 6 specimens of *I. subangularis* from Waldron, including Hall's types, gives the following relative dimensions; I have added those of Hall's Bridgeport specimen of the latter species and of a cast in my own collection, also from Bridgeport, in the same condition in which *I. corbis* is found:

| | Height to width | | | Expansion of calyx from RR to $IIBr_4$ |
|---|---|---|---|---|
| | at $IIBr_4$ | at IAx | of $IBr_1$ | |
| *I. corbis,* 15 specimens............. | 1 : 1.6 | 1 : 1.4 | 1 : 4.4 | 1 : 2 |
| *I. subangularis,* 6 specimens........ | 1 : 1 | 1 : 1 | 1 : 2.4 | 1 : 1.7 |
| Hall's Bridgeport spm. XXXIV, 7.. | 1 : 1 | 1 : 1 | 1 : 2 | 1 : 1.5 |
| New Bridgeport spm. XXXIV, 8... | 1 : 1 | 1 : 1.07 | 1 : 2.3 | 1 : 1.6 |

The differences of proportion in general contour would be emphasized if we had the external surface instead of merely the internal casts of *I. corbis,* because the calyx wall is thinnest below the secundibrachs; but the dimensions above given are sufficient to prove that the two species are about as different in type as we can expect to find in a genus like *Ichthyocrinus.* Hall's Bridgeport specimen, as the table shows, falls into line with the Waldron specimens, and not in any respect with those from Chicago. It also exhibits in a marked degree the angularity in the lower part caused by the prominence of the brachial series. This feature is usually absent in the Chicago casts, though some specimens of *I. corbis* show it to a slight extent. In my specimen (Pl. XXXVI, figs. 6*a, b*) which has the plates in the halves of two contiguous rays preserved from IIBr$_2$ up, and which is of maximum size, there is only the faintest trace of a median ridge, although the higher ray divisions preserved in other rays are more or less angular on the dorsal side. But in the internal cast of *I. subangularis* from Bridgeport, in addition to the characteristic dimensions given in the foregoing table, the figure (Pl. XXXIV, fig. 8) shows the radial angularity and peculiar contour of the base, precisely as in the Waldron specimens. This specimen is better than Hall's in that it has the outline of the base perfectly preserved, even to the cast of the axial canal.

Hall in the discussion with Winchell and Marcy (20th Report, p. 385) mentions one of the casts showing "the obscurely angular form of the lower part of the body." This specimen, which lies in the same tray with his type from Bridgeport in the Hall collection at the American Museum, undoubtedly shows the angularity mentioned with considerable distinctness. It has but little of the usual distortion of *I. corbis,* and it is interesting to find that its proportions are intermediate between those of the two species. It is rather singular that of the only two specimens from the Chicago beds obtained by Hall, one should be a good example of *I. subangularis* and the second a very evident intermediate type; neither of them represents the prevalent form, and after seeing them we can readily understand why Hall insisted on the specific identity of the species from the two areas.

In the List of Types published by the American Museum the locality of Hall's figure 15, plate 11 of the 20th Report is given as Racine, Wisconsin, although Hall himself stated it as Bridgeport. This locality is within the present limits of the city of Chicago, at about the intersection of Thirty-fifth street and Archer avenue. I am informed by Mr. E. E. Teller of Milwaukee, President of the Wisconsin Natural History Society, who knows the history of all the collections ever made in the Illinois-Wisconsin Niagaran area, and has himself made extensive collections there, that *Ichthyocrinus* has never been found at any other locality than Bridgeport, where it occurred in the uppermost layers of the quarry. It does not occur at Racine, or other well-known Wisconsin localities, and the enormous excavations made during the construction of the Chicago drainage canal have not to my knowledge produced a single specimen.

The imbrication of the plates produced by the raised transverse margins of the brachials is present in two of my specimens of *I. corbis* having part of the plates intact; it is less evident on Hall's Bridgeport specimen, and not at all on those from Waldron.

I have not been able to find in any specimen of *I. corbis* the least trace of the infrabasals, though in several the bounding sutures of the basals are beautifully distinct, and there is seen projecting from them the obtusely angular object which Winchell and Marcy took for the stem (Pl. XXXVI, figs. 3*a, b*). There is little doubt that the infrabasals in this species were in the same condition as those of *I. gotlandicus,* very small and largely atrophied, and that this projection is the cast of the enlarged axial opening left after their resorption (compare Pls. XXXV, figs. 4*b*, 5, and XL, 9*b*). It is perfectly preserved in the specimens above mentioned, distinctly showing the pentapetalous outline at the lower end; and it is further interesting because the length to which it projects, which is not over a millimeter, no doubt represents the full thickness of the calyx wall at the base. This is but little greater than is found higher up, and it shows that there was no extraordinary growth of calcareous matter at this point to render the external contour specially different from the internal. The basals themselves are very small, though they would be somewhat larger at the exterior; and in view of the apparent condition of the infrabasals, and what we know of their relative proportions in other species, it is clear that the basals were nearly, if not quite, covered by the column, and not visible externally in a side view.

The straight sutures on which Winchell and Marcy laid so great stress are not a valid specific character. As before explained in the chapter on Morphology, the sinuous suture lines and so-called " patelloid plates " throughout this entire group are only external surface characters which disappear by wear, all sutures becoming straight a short distance inward. The fact as to this particular species is beautifully shown by the specimens preserving part of the test figured on Plate XXXVI, figures 6*a, b,* where both kinds of sutures are shown in the same parts of the same specimen.

This species is distinguished from *I. laevis,* which is nearest like it in the size and imbrication of the plates, by the pyriform crown and larger basals of that species. It is nearest in general form and probably in details of the base to *I. gotlandicus,* the type specimen of which was originally identified by Angelin as *I. laevis,* but it differs in the absence of ornamentation.

*Types.* The original specimens used by Winchell and Marcy are understood to be in the Northwestern University at Chicago, but as none were figured they cannot be identified. Those figured herein are in the author's collection.

*Horizon and locality.* Silurian, Racine dolomite beds of the Niagaran Group; Chicago, Illinois, at quarries about the junction of Thirty-fifth street and Archer avenue, formerly known as Bridgeport.

### **Ichthyocrinus devonicus** n. sp.

*Plate XXXV, figs. 17a-c*

A small species of the type of *Ichthyocrinus gotlandicus,* but with calyx more broadly spreading and somewhat pyriform in lower part. Height to width at upper IIBr, 1 to 2; spread of calyx to that level, 1 to 5. Crown ovoid to low pyriform; no radial ridges. Surface smooth; plates not imbricated. Crown, about 30 mm. high by 25 mm. wide; base, 5 mm.

IBB, BB, and RA covered by the column. IIBr 3; IIIBr 3 to 7; height to width of Br above IBr, about 1 to 3.5. Column large at base, unknown below proximal columnal.

This species is founded upon a single specimen from the Helderbergian of Tennessee—the only Devonian representative of the genus from American rocks. It is of the type of *I. corbis* and *I. gotlandicus* in the extreme reduction of the basal elements, and it agrees with the latter and differs from all other American species of this genus in having but three IIBr; these characters produce a short and broadly spreading calyx.

*Type.* Author's collection.

*Horizon and locality.* Devonian, Linden formation of the Helderbergian; Benton County, Tennessee.

### **Ichthyocrinus bohemicus** (Barrande MS.)

*Plate XXXVI, fig. 15*

*Lecanocrinus bohemicus* Barrande MS., Waagen and Jahn in Barrande, Syst. Silur. centre Bohême, VII, 1899, p. 29, pl. 60, figs. 11, 12, 13, pl. 61, figs. 6, 7, 8, 9.

*Ichthyocrinus* ? sp. indet., Waagen and Jahn in Barrande, Syst. Silur. centre Bohême, VII, 1899, p. 29, text-fig. 8.

*Ichthyocrinus bohemicus,* Bather, Ann. and Mag. Nat. Hist., (7) VI, 1900, p. 114.

Messrs. Waagen and Jahn devote two pages and seven figures of the ponderous tome above cited to a fragment from the White limestone, stage $F^2$, of Koneprus, Bohemia. It was originally labeled by Barrande *Lecanocrinus bohemicus,* but Waagen and Jahn incline to refer it with doubt to *Ichthyocrinus,* in which they are clearly justified. Enough remains of the specimen to indicate its generic affinities, and that it belongs to a species with a low ovoid crown, probably small basals, and perhaps ornamented surface; it belongs to the type of species like *I. gotlandicus* or *I. corbis,* and is of interest chiefly to show the occurrence of the genus in Bohemia.

*Type.* In the Collection Barrande, Prague, Bohemia.

*Horizon and locality.* Lower Devonian, stage $F^2$ (perhaps=Helderbergian) Koneprus, Bohemia.

## CLEISTOCRINUS nov. gen.

(κλειστός, closed; κρίνον, lily)

*Plate XXXVIII, figs. 1-2*

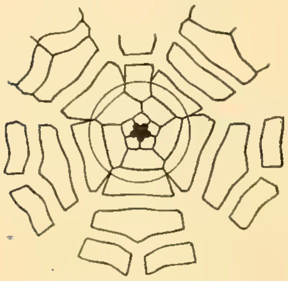

Fig. 37. *Cleistocrinus*

Ichthyocrinidae with rays in contact except at anal side. Crown expanding distally. Infrabasals entirely within the ring of basals, or wanting. Posterior basal not differentiated. Radianal in form of radial under right posterior radial. Anal *x* followed by others in series, usually not connecting with basal. Interbrachials wanting. Primibrachs two. Arms unknown. Column large, covering basals.

*Genotype.* *Calpiocrinus humilis* Angelin.

*Distribution.* Silurian, Wenlock Group; only known from Gotland.

I have proposed this genus to receive a form which, although represented by rather imperfect material, is nevertheless of a very definite type, and occupies a place in the present family which cannot be confounded with any other. It is founded upon the Silurian species described by Angelin as *Calpiocrinus humilis.* His figures show very little of the essential structures which make the form important, and which are now clearly brought out by new figures made after further preparation of the specimens, especially by removal of the stem ossicles filling the basal cavity in one of them, thus enabling us to see the true arrangement of plates which was before obscured.

This form stands close to *Ichthyocrinus,* but with the posterior rays partly separated by anal plates; as in that genus the posterior basal is not differentiated, but a strong series of anal plates is interposed above the level of the radials, one of which and the radianal meet below, entirely separating the anal series from the basal circlet. This is a very unusual structure in crinoids, but is found also in one species of *Calpiocrinus;* therefore I have not made it an absolute generic character, and a species with anal plate coming down to the basal would be admitted. The extreme diminution of the base, however, leads me to think that the non-differentiation of the posterior basal is probably a well correlated character. There is in one specimen a slight tendency to development of interbrachials, but it is evidently only sporadic, as is seen occasionally in *Metichthyocrinus.* A rather clear line of succession leads from this Silurian type through *Synaptocrinus* in the Devonian with no radianal, greatly elongated posterior basal and no connecting anal structures, to *Euryocrinus* in the Carboniferous, which adds the anal series and interbrachials together with another primibrach.

The atrophy of infrabasals so frequent in this family has proceeded to the extreme of resorption in this genus. In the two specimens known not the slightest trace of these plates remains within the ring of basals; not only so, but the basals themselves seem to be on the verge of suppression. In one specimen they are much encroached upon by the axial canal, and in the other nearly half of them have disappeared (Pl. XXXVIII, figs. 1*d*, 2*b*). The basal structures are deeply buried under the large proximal columnal to an extent only paralleled in some species of *Dactylocrinus;* here the basals, radials, and a part of the first primibrachs are involved in the column facet. None of the specimens are sufficiently preserved to show the arm structure, but it was probably not much different from that of *Ichthyocrinus.* Only the one species is known.

### **Cleistocrinus humilis** (Angelin)

*Plate XXXVIII, figs. 1-2*

*Calpiocrinus humilis* Angelin, Icon. Crin. Sueciae, 1878, p. 12, pl. 23, figs. 28, 28*a*, *b*, *c*, pl. 26, fig. 17.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 39.

Type of the genus.

A small species. Calyx rapidly spreading; height to width at top of IAx, 1 to 3.6; spread from base, 1 to 2.2. Side outline a low curve; cross-section circular; base very large, deeply concave, involving all plates below IBr. Surface smooth. Full dimensions of crown unknown; the principal specimen is 18 mm. wide at top of IBr; basal concavity 8 mm. measured from perimeter of column; actual diameter of basal ring, 2.5 mm. IBB resorbed, and sometimes in part also the basals which are very small. RA as large as some of the radials, which are somewhat irregular in size. Anal *x* a long plate, sometimes rising as high as the axillary IBr, and followed by one or more others in series; it is angular or truncate below, supported by l. post. R and RA. RR small, much wider above than below; IBr continue to increase in width in about same degree. Superior parts unknown. Column very large, composed next to the calyx of thin ossicles.

The species is only known from two specimens, neither of which has the rays preserved above the primibrachs, and of these the right posterior axillary is wanting in both. Figures 2*a*, *b* show that the second primibrach in that ray alone is not axillary; so there must be a third above it, and the small unsymmetric plate at the base of the ray in both specimens must be a radianal.

*Types.* Riks Museum, Stockholm, Sweden.

*Horizon and locality.* Silurian, Wenlock Group, horizon *f;* Gotland, Sweden.

## **CLIDOCHIRUS** Angelin

### *Plate XXXVII*

*Clidochirus* Angelin, Icon. Crin. Sueciae, 1878, p. 12.—Wachsmuth and Springer, Revision Palaeocrinoidea, I, 1879, p. 39.—Von Zittel, Handbuch Palaeontologie, I, 1879, p. 355.—Bather, Rep. British Assoc. for 1898 [1899], p. 923; Treatise on Zoology (Lankester), pt. 3, 1900, p. 188.—Springer, Amer. Geologist, XXX, 1902, p. 94; Jour. Geology, XIV, 1906, pp. 479, 516.—Zittel-Eastman, Textbook Paleontology, 1913, p. 204.

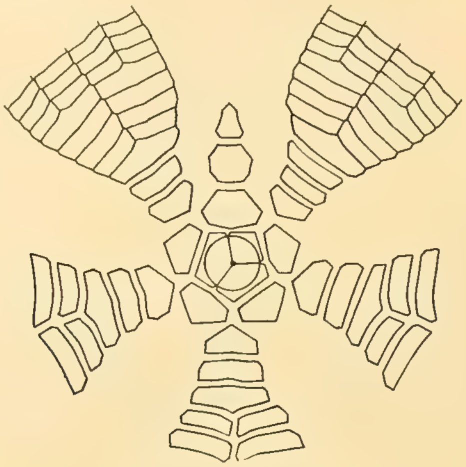

FIG. 38. *Clidochirus*

Ichthyocrinidae with rays in contact except in lower part at the posterior side. Crown elongate, expanding above radials. Radianal in primitive position under right posterior radial, resting on basals and touching right anterior radial. Infrabasals variable; either large, exposed above the column, or small, entirely concealed. Basals large, exposed above the column. Anal *x* alone, or followed by others in single vertical series, arched over by brachials. Primibrachs two. Arms dichotomous, interlocking. Column large, with or without proximal enlargement. Otherwise similar to *Ichthyocrinus*.

*Genotype.* *Clidochirus pyrum* Angelin.

*Distribution.* Silurian to Devonian (Lower Carboniferous?); Sweden and the United States.

This genus was founded by Angelin[1] upon a single species and specimen from bed *c* at Wisby, Gotland. His generic diagnosis, translated, is as follows:

> Body short, pyriform. Calyx cyathoid, inequilateral. Radials variable, three or four. Anals distinct, four, in a longitudinal series.

This would have been well enough as far as it goes if given in connection with a correct definition of *Ichthyocrinus*, although it does not agree with his specific description, nor with the facts in regard to the number of anal plates in the series. But Angelin placed it under a new family, Homalocrinidae, along with *Lecanocrinus* and *Calpiocrinus*, without recognizing its close relation to *Ichthyocrinus*, although he figured under *I. pyriformis* (*op. cit.*, pl. 22, fig. 6) an excellent specimen of his type species *Clidochirus pyrum* (see my Pl. XXXVII, figs. 3*a*, *b*). His account of the genus contained nothing as to the composition of the base, for the very good reason that it was broken off in his specimen—a fact which does not appear in his restored figure (*op. cit.*, pl. 22, fig. 23), but which is clearly shown by Mr. Liljevall's accurate drawing of the same specimen (Pl. XXXVII, fig. 1).

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[1] Iconocraphica Crinoideorum Sueciae, 1878, p. 12.

Wachsmuth and Springer [1] did not recognize *Clidochirus*, but considered it a synonym of *Calpiocrinus*, a genus of which no one at that time had a very clear idea. In making this disposition we noted that *Clidochirus* differed in having " four instead of three primary radials—variations which may be expected even in the same species "—illustrating again the notion which prevailed as to the total depravity of the brachial system in this group, due to a then unrecognized element, the radianal. The genus was also ignored by Von Zittel, both in the Grundzüge and in the Text-Book of Paleontology by Zittel and Eastman.

Bather [2] reinstated the genus, placing it in his family Ichthyocrinidae along with *Pycnosaccus, Lecanocrinus, Mespilocrinus, Nipterocrinus* and *Ichthyocrinus;* but he did not understand its real structure, and diagnosed it as without a radianal—his main distinction for it being the presence of three anals in a vertical series.

Angelin's specimen, although imperfect, preserved part of the posterior basal, the anal plates, and the extra plate in the right posterior ray, all of which were correctly brought out in his figure; but at the time of the foregoing opinions the significance of that extra plate was not understood, it being supposed to be a mere irregularity characteristic of the group. The discovery of the fact that the plate is a radianal in its primitive position like that of *Ichthyocrinus* [3] established for *Clidochirus* a distinct position among the genera of this group which is easily expressed; but its family relations are perplexing. It is an intermediate form between the Lecanocrinidae and Ichthyocrinidae. Upon the preponderance of the base and stem characters it agrees better with the former, but as to both of these there is considerable variability.

In most of the Gotland specimens, but not all, the infrabasals are prominent on the outside; in some they are concealed by the column (Pl. XXXVII, fig. 6). Both types of base are found among the American species, and in the two Helderbergian forms the infrabasals are thoroughly withdrawn from the exterior. So also some specimens have a tapering column, while in others it is straight from the calyx down. In view of the instability of these characters we may attach greater weight to the general facies, which is decidedly that of the Ichthyocrinidae, among which I have placed it as a variant or transition form.

In habitus the genus is strongly similar to *Ichthyocrinus*, having the same conical expansion of the calyx by increase in width of the brachials following small radials; the radianal is of similar form and like position. But in addition to the large anal plate interposed between the posterior rays, it differs in the usually large basals.

The construction of the anal area is an extension of the plan of *Lecanocrinus;* instead of one large plate there may be several, but in each case the distal end is sharply angular, fitting closely by sutural connection to the adjacent rays, which come together above it like an arch.

The structure of the stem is a further indication of an intermediate position. The proximal columnals are usually not so wide as in *Ichthyocrinus;* they are short, but with more tendency toward the development of still thinner internodals, and they change into more uniformly long columnals further down,—both of which characters are found in the column of *Lecanocrinus*. The arrangement of the proximal columnals appears very distinctly in the young specimen of *C. pyrum* (Pl. XXXVII, fig. 2), where the intercalation of very thin ossicles between thicker and wider ones is well shown.

*Clidochirus* has hitherto been an exceedingly rare and little known genus, but thanks to the activity of Mr. Liljevall the material for its elucidation has been greatly augmented since

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[1] Revision Palaeocrinoidea, pt. 1, 1879, p. 39.

[2] In Lankester, Treatise on Zoology, pt. 3, 1900, p. 188.

[3] Springer, Journal of Geology, vol. 14, 1906, p. 479.

Angelin's time; and the geographical distribution of the genus has been further extended by the discovery of three well-marked species in America, extending its stratigraphic range into the Lower Devonian. The four certain species may be arranged as follows:

### The Species of Clidochirus

I. Surface ornamented with pustules and wrinkles.
  Crown pyriform.
    BB and IBB large.
      RA about as large as RR.
        Br about 3 times wider than high..................................*C. pyrum.*
II. Surface smooth.
  Crown elongate, evenly curved.
    Base narrow, BB and IBB large.
      RA smaller than RR.
        Br less than 3 times wider than high..........................*C. americanus.*
  Crown low, angular.
    Base broad; BB and IBB small.
      RA about equal to RR.
        Br strongly convex; sutures indented.........................*C. keyserensis.*
  Crown conical, evenly curved.
    Base narrow. BB and IBB large.
      RA smaller than RR.
        Br 4 times wider than high..................................*C. schucherti.*
III. A variant with 3 IBr, perhaps of this genus, or a successor
        to it; from the Lower Carboniferous........................(?) *C. greenei.*

## **Clidochirus pyrum** Angelin

*Plate XXXVII, figs. 1-6*

*Clidochirus pyrum* Angelin, Icon. Crin. Sueciae, 1878, p. 12, pl. 22, fig. 23.—Springer, Jour. Geology, XIV, 1906, p. 479, pl. 6, fig. 7.
*Calpiocrinus pyrum* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 39.
*Ichthyocrinus pyriformis* Angelin (in part), Icon. Crin. Sueciae, 1878, pl. 17, fig. 6.

Type of the genus.

Species attaining a large size. Crown pyriform, with truncate base; expanding gradually from base. Height to width at upper IIBr, 1 to 1; spread of calyx from base to same level, 1 to 4; cross-section circular; side outline straight or slightly concave; no radial ridges; base relatively broad. Surface marked by small pits on the lower brachials, becoming confluent above and forming numerous parallel wrinkled grooves longitudinally disposed across the plates from margin to margin. Medium crown, 24 mm. high by 18 mm. wide at top of $IIBr_4$; base, 5 mm.

IBB large, visible in pentagonal outline above the column. BB large, not touching column; posterior B larger than the others, and supporting two large anal plates in vertical series, and sometimes a third smaller one; the upper one angular above. RA about the shape and size of RR in other rays. Brachials evenly curved; above IBr about three times wider than high, relatively narrower in young specimens. IIBr 3 or 4; IIIBr 5 to 7 or more; one more bifurcation visible before infolding; arms not tapering rapidly above IIBr. Column large; proximal columnals as wide as the base, thin, diminishing somewhat in width downward and gradually changing to longer ossicles of about equal length.

Angelin's specific description is but little more definite than the generic diagnosis. The latter calls for four anal plates; the former, more correctly, for three. The surface ornament is the only other point mentioned, and this is important because somewhat different from that of *Ichthyocrinus*. There it is produced by means of small raised granules, or pustules, scattered over the surface, which by confluence become ridges in some places. Here the process is reversed, and we have depressions instead of elevations, producing pits and grooves. The description was based upon a single specimen from bed *c* at Wisby (*op. cit.*, pl. 22, fig. 23), imperfect at the base, which Angelin restored in his figure without taking any account of infrabasals. At the same time he figured on plate 17, figure 6, a weathered specimen also from Wisby (bed *d*), with stem attached, which showed the prominent infrabasals and very large basals of the genus; but he did not recognize its relationship, and labeled it *Ichthyocrinus pyriformis*. I have given a new figure of this specimen in the same view as Angelin's, together with a view of the anal side, which Mr. Liljevall has since cleaned, showing the lower part of the calyx, and the base detached from the stem (Pl. XXXVII, figs. 3*a*, *b*).

I also give an accurate drawing of the type specimen, showing just what is preserved at the base, with its relation to the missing parts indicated. Inspection of these figures leaves no doubt as to where Angelin's plate 17, figure 6 belongs. It is as stated a weathered specimen, and the surface markings are not preserved. These are well shown in the type specimen, but still better upon a young specimen from the same locality and horizon, figure 2 on Plate XXXVII. The change from scattered pits in the lower part to parallel longitudinal wrinkles on the higher brachials is very distinct; the small specimen also shows very plainly the exact construction of the proximal columnals, and how they differ from those of *Ichthyocrinus*. These three specimens give a very intelligible representation of the species, which seems well characterized by them.

There is, however, in addition to these a very large specimen from Tofta (horizon *d*) showing such a great development in size that it may possibly belong to a different species (Pl. XXXVII, figs. 5*a*, *b*, *c*). It is fully twice as large as any of those before mentioned, and has some tendency to angularity on the distal portion of the higher brachials. It shows no surface ornament, but as it is a weathered specimen this may be due to erosion. It has all the appearance of a very mature individual, and might readily be considered merely as such, if it were not for the fact that there are in the Riks Museum at Stockholm, from the same horizon at Wisby, two crushed fragments of specimens even larger than this, which show the same tendency to angularity in the higher brachials; but they also show, very plainly, the surface markings characteristic of the type specimen (Pl. XXXVII, figs. 4*a*, *b*). On the whole it seems difficult to point out any difference between these larger specimens and the others which may not be due to individual growth or condition of preservation; and the fact that there are three specimens of this size would rather indicate that the habitus of the species is large, and that the type was probably undersized.

*Type.* Riks Museum; Stockholm, Sweden.

*Horizon and locality.* Silurian, Wenlock group, horizons *c, d;* Wisby and Tofta, Island of Gotland.

### **Clidochirus americanus** n. sp.

*Plate XXXVII, figs. 7-8*

A small species. Crown elongate pyriform, height to width at upper IIBr about 1 to 1; spread of calyx from base to same level, 1 to 2.6. Surface smooth. Maximum crown 25 mm. high by 15 mm. wide at upper IIBr; base 3 mm.

IBB visible in pentagonal outline. BB small. RA much smaller than RR in other rays. Anal *x* alone, angular above. IIBr 3 as a rule; IIIBr 4 or more; one more bifurcation visible. Brachials not more than twice as wide as high, evenly curved, without median ridges, tapering rapidly above IIBr. Column small, not expanding at top.

This species is founded on two specimens from the top of the Medinan group of Ohio, a horizon below that of the shales of Indiana and New York, and perhaps corresponding to a horizon lower than beds *c* and *d* in which the Gotland species occur. It is a slightly more elongate form than *C. pyrum*, as the proportionate dimensions averaged from all the specimens show, and the brachials are proportionately longer and narrower. The size is about the same as the average of that species leaving out the very large specimens. The difference in size of the radianal between the two species is quite remarkable, and seems to be constant. In this one it has the appearance of a reduced or undeveloped plate, much like that in some specimens of *Ichthyocrinus;* here also the succeeding radial is somewhat ill-formed. The brachials throughout are proportionally longer than in either of the other species, producing greater elongation of the crown, even where the others have a larger number of plates between the bifurcations.

The stem, as shown in the largest specimen (Pl. XXXVII, fig. 8), has a little different aspect from that of the Gotland specimens, being narrower in the proximal part, and the joints further down more rounded. It shows a marked alternation of short and long columnals diminishing distally until only the longer ones are left. The surface in both specimens is imperfectly preserved, and they show no trace of the characteristic ornamentation of the type specimen of *C. pyrum.*

No other specimens have been found besides the two figured.

*Type.* Author's collection.

*Horizon and locality.* Silurian, Brassfield formation at the top of the Medinan group; Dayton, Ohio.

### **Clidochirus keyserensis** n. sp.

*Plate XXXVII, figs. 9-11*

A medium sized species. Crown angular, broadly rounded below, expanding rapidly from base; base small. Height to width at $IIBr_3$, 1 to 2.3; spread of calyx from base to IAx, 1 to 4; cross-section at IIBr decagonal, with deep depressions at the interbrachial sutures. Brachials thick, highly curved and sometimes angular; transverse sutures strongly indented. Surface without ornament. Maximum crown, 33 mm. high by 22 mm. wide at top of $IIBr_3$. Base at column facet, 5 mm.

IBB very small, invisible beyond the column. BB small for the genus, touching the column, and lying so flat as to be but slightly visible in a side view; post. B supporting a narrow anal series of three or more plates. RA similar to R in other rays. Br not only highly arched longitudinally, but strongly sloping to the proximal and distal margins, leaving deep, angular depressions at the sutures, and strongly buttressed side margins. IIBr 3; IIIBr 4 on inner rami of dichotom, and 5 to 7 on outer. Arms infolding beyond the 4th bifurcation. Column small, cylindrical, with nearly uniform ossicles, slightly alternating in length.

This species is distinguished from all others by its broadly rounded crown, small basal and infrabasal plates, and highly arched and buttressed brachial plates. It wholly lacks the pyriform or elongate contour and evenly curved plates of the type, or of its American congeners. The infrabasals have retreated to the column facet as in *Ichthyocrinus*. The figures indicate a faint surface ornament, which proves to be not organic, but the result of chemical action, affecting most of the crinoids of the same locality. The species is not uncommon in the Helderbergian beds, at Keyser, West Virginia.

*Types.* In the collection made by Professor Frank Hartley, of Cumberland, Maryland, now belonging to the author.

*Horizon and locality.* Helderbergian, Keyser formation; Keyser, West Virginia.

### **Clidochirus schucherti** (Talbot)

*Plate XXXVII, figs. 12-13*

*Ichthyocrinus schucherti* Talbot, Amer. Jour. Sci., XX, 1905, p. 30, pl. 3, fig. 1 and text-fig. 4.

A medium sized species. Crown short, conical, with rather narrow base, expanding uniformly to about the middle IIIBr, and becoming strongly contracted above that by the infolding of the arms. Spread of calyx from base to upper IIBr, about 1 to 3; height to width at that level, 1 to 1.5; side outline but slightly convex; cross-section circular; base larger than proximal columnal. Surface smooth. Crown of maximum specimen, 27 mm. high by 20 mm. wide at upper IIBr; width of base at IBB, 6 mm.

IBB small, not visible beyond the column. Basals large, showing a full pentagon in side view. Anal *x* large, perhaps followed by another. RA smaller than R in other rays. Br 4 times wider than high, evenly curved, without surface angularity or imbrication; IIBr mostly 4, abnormally 8; IIIBr 5 to 8 or more, with another bifurcation visible in some rays. Column of good size, proximal columnals not enlarged; alternating nodal joints becoming rounded a short distance below.

This species was founded upon a specimen from the New Scotland beds of the Helderbergian of New York, and described under *Ichthyocrinus*. Miss Talbot's description and diagram,[1] while in other respects excellent, are not correct in representing four primary plates in each ray. The specimen is partly imbedded in the matrix, leaving only three rays exposed, and these injured by weathering, so that the plates can be well distinguished in only two of them. One has four, the other three. No other species or specimen of this family is known in which there are four primary plates (radial and three primibrachs) in all the rays, except in the Carboniferous. From these facts we must infer that the ray with the four plates is the right posterior with the radianal in primitive position, and that there are a radial and two primibrachs in each of the other four rays.

This is confirmed by the discovery of another specimen from the same horizon in New York in which the crown is free and the anal structures clearly shown, thus leaving no doubt as to its generic position under *Clidochirus*. The stem in the type specimen also is that of this genus, and not of *Ichthyocrinus*. This species added to the one from West Virginia, brings the range of the genus strongly into the Devonian.

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[1] American Journal of Science, vol. 20, 1905, p. 30, text-fig. 4.

*Type*. Peabody Museum, Yale University, New Haven, Connecticut. The original of Plate XXXVII, figures 13*a, b,* was found by the veteran collector Frederick Braun and by him contributed to my collection in aid of this work.

*Horizon and locality*. Devonian, New Scotland formation of the Helderbergian; Clarksville and Schoharie, New York.

### (?) **Clidochirus greenei** (S. A. Miller)

*Plate XXXVII, fig. 14*

*Ichthyocrinus greenei* Miller, Geol. Surv. Indiana, Adv. Sheets 18th Rep., 1892, p. 52, pl. 8, fig. 3 (Final Report, 1894, p. 306).—Springer, Jour. Geol. XIV, 1906, pp. 490; (? *Metichthyocrinus*) 517.

A large species. Crown elongate, pyriform; 50 mm. high by 21 mm. wide at widest part, about IIIBr$_1$; height to width at IIBr$_4$, 1 to 0.8; at IAx, 1 to 0.9; spread of calyx from base to IIBr$_4$, 1 to 2.8; cross-section circular, side outline concave or straight, continuous with stem. Base truncate. Surface smooth.

IBB large, visible as broad, low pentagons. BB small, wider than high. RR small, about one and one-half times wider than high. IBr and IIBr about twice as wide as high, increasing in width from RR upward; IBr 3; IIBr 4; IIIBr 5 to 10 or more, with other bifurcations following. Rays interlocking at least to upper IIBr, abutting and infolding above, branching to at least 4 bifurcations; plates evenly curved, with but little convexity. No interbrachials, anal side unknown. Column large, continuous with calyx, with a proximal enlargement composed of short columnals increasing in length downward as far as preserved.

This species was founded upon a single specimen, described by S. A. Miller as *Ichthyocrinus*. It is said in the description to be from the Keokuk limestone of the Lower Carboniferous, and no other example of it has been discovered. Three rays are exposed, while the other side of the crown lies imbedded in a coarse, siliceous limestone harder than the fossil, thus effectually preventing any further exposure of the rays by cleaning. Unfortunately the part concealed is the posterior side, and we do not know what the anal structure is; from what can be seen of the calyx there is room for a narrow single series of anals. The large basals and upstanding infrabasals remove it from *Ichthyocrinus*.

The aspect of this fossil is nearer that of *Clidochirus,* to which it would clearly belong if possessing a series of anal plates, except for the number of primibrachs; in the visible rays this is clearly three, which if constant for the others would separate it from all normal forms of this and related genera. It would then (assuming its recorded horizon to be correct) have to stand as a Carboniferous representative of *Clidochirus,* requiring the recognition of a new genus bearing the same relation to the former as *Taxocrinus* to *Protaxocrinus*—the development of the rays thus correlating with its stratigraphic position, and being parallel to similar progressions in the other families. The specimen in this respect may be exceptional, and in the absence of further information as to its essential characters it is advisable to place it with doubt, and provisionally, under *Clidochirus*.

*Type*. Formerly in the collection of Mr. George K. Greene, New Albany, Indiana, now in the American Museum, New York.

*Horizon and locality*. (?) Lower Carboniferous. In the description the unique specimen is said to be from the Keokuk Group, Muldraugh Hill, Kentucky. There is a possibility that it may have been derived from Niagaran rocks in Jefferson County, Kentucky. Such a geological position would confirm the reference to *Clidochirus* as a variant.

## **SYNAPTOCRINUS** nov. gen.

(συναπτός, joined; κρίνον, lily)

*Plate XXXVIII, figs. 3-6*

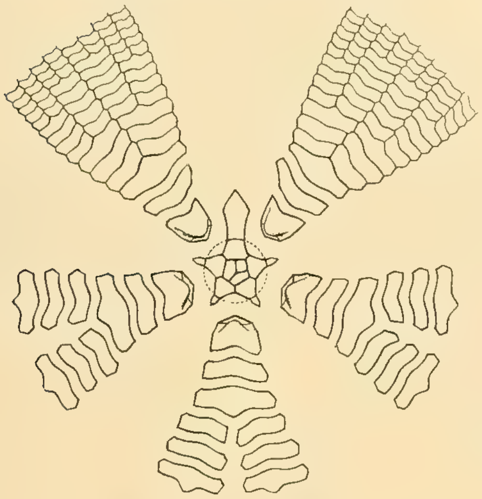

FIG. 39. *Synaptocrinus*

Ichthyocrinidae with rays usually in contact all around. Crown elongate, expanding distally from radials up. Infrabasals entirely within the ring of basals. Posterior basal elongate, much larger than others. No radianal. Anals and interbrachials usually wanting. Primibrachs two. Arms dichotomous, interlocking, or closely appressed. Column strong, enlarging proximally, covering a large part of the basals.

*Genotype. Forbesiocrinus nuntius* Hall.

*Distribution.* Devonian; United States.

The type of the Devonian species upon which this genus is founded is small and imperfect, and most of the specimens since found have been of similar character. The discovery of a large and finely-preserved specimen, which has been perfectly cleaned on all sides, disclosed a well-marked type which could not be referred to any genus heretofore established. It has all the general characters of the family, and superficially bears a strong resemblance to *Wachsmuthicrinus,* from which the dichotomous arm structure and highly differentiated posterior basal at once distinguish it.

In all specimens known there is an entire absence of interbrachial or anal plates, the rays being in contact throughout except at the posterior side where they are separated in the lower part by the posterior basal. Considering the disproportionate size of this plate we should expect to find one or more anal plates succeeding it; but it is doubtful if they occur, for in all specimens thus far observed the posterior basal terminates in a point, fitting accurately between the sloping wings of the first primibrachs, or of the overhanging radials. This is probably a constant generic character, but if as in the case of *Wachsmuthicrinus* interbrachials should be found in some specimens, the genus would stand upon its other characters. It is morphologically intermediate between *Cleistocrinus* and *Euryocrinus,* as it is also in geological position.

Only the one species is known.

### **Synaptocrinus nuntius** (Hall)

*Plate XXXVIII, figs. 3-6*

*Forbesiocrinus nuntius* Hall, 15th Report New York State Mus. Nat. Hist., 1862, p. 124 (Separate, p. 96); Bull. I, New York St. Mus., Photographic Plates, 1872, pl. 1, fig. 12.

*Taxocrinus nuntius,* Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, IX, 1865, p. 140.—Wachsmuth and Springer, Revision Palaeocrinoidea, I, 1879, p. 49.

*Rhodocrinus* (*Taxocrinus*) *nuntius,* Shumard, Trans. Acad. Sci. St. Louis, II, 1866, p. 398.

Type of the genus.

Specimens usually small, but may attain large size. Crown elongate, widest about the third bifurcation, where height to width is 1 to 1.3; spread of calyx from perimeter of column facet to IAx, 1 to 2.5; cross-section at that level stellate; side outline straight; base concave, the concavity filled by column and including the basals except for small points sometimes exposed. Rays strongly elevated and angular in the middle; primary plates and axillaries nodose; sutures sinuous. Surface strongly ornamented with small papillae, tending to coalesce into longitudinal wrinkles. A large crown is 20 mm. high to about fourth bifurcation, probably extending considerably higher; width, 24 mm.; base outside of column, 7 mm.

IBB small, filling about half the diameter of column facet. BB small, visible only in small angles beyond the column, except the post. B, which is greatly elongated, extending to the full height of RR, and terminating in an acute angle, leaving no surface for attachment of anal plates. RR wider above than below, elevated into large, angular, median nodes resembling short spines projecting downward over the proximal columnals, with lateral margins flattened toward the sutures; similar nodes surmount the two primibrachs and all axillaries beyond, the intervening brachials being elevated and sharply angular in the middle. All brachial plates are much wider than long, and have the lateral margins abruptly deflected from the median elevated part into low, wing-like buttresses, which meet at the interradial sutures and interlock; just at the edge they often have a slight elevation or fold parallel to the median line, strongly resembling rows of interbrachial plates. IBr increasing rapidly in width upward in line with margins of RR. IIBr 3; IIIBr about 4 to 6 or 7, the longer intervals being in the outer ramii, some branches bifurcating once more. Column large next to the calyx, where it fills the concave base; it diminishes gradually for about a dozen moderately thick, rounded and equal ossicles, with thin projecting rims; below that they become thicker and more rounded, with large ones at intervals of four or five.

The description of brachial structures is chiefly taken from the large specimen obtained at a different locality from the type (Pl. XXXVIII, figs. 4*a, b*); the nodes are less accentuated in smaller specimens, but the angularities and general features of surface marking are the same. Out of four well marked specimens, three are about equally small; but notwithstanding the great disparity in size of the large one I am unable to see any specific difference between them. The sharply angular distal end of the posterior basal, constant in all the specimens, precludes any suggestion of anal structures. Since the foregoing description was prepared I have obtained from the type locality in Erie County another still larger specimen, measuring 45 mm. high by 35 mm. wide. It is so encrusted with pyrites that the detailed structures are obliterated, but the nodose axillaries are almost spiniferous.

Hall in describing the species noted its remarkable resemblance to "*Forbesiocrinus*" *thiemei,* now the type of *Wachsmuthicrinus,* as well as its difference from that species in arm structure. This resemblance is heightened by the nodose and spiniferous character of the axillaries so conspicuous in the specimens found since his time.

*Types.* Hall's original is in the American Museum of Natural History, New York. That of figure 5 is in Columbia University. The others are in the author's collection.

*Horizon and locality.* Middle Devonian, Hamilton Group; Eighteen Mile Creek, Erie County, and Bellona, Yates County, New York.

## **DACTYLOCRINUS** Quenstedt

*Plate XLI*

*Dactylocrinus* Quenstedt, Petref. Deutschlands, IV, 1876, p. 520.—Von Zittel, Handbuch Palaeontologie, 1879, p. 354.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 3, 1886, p. 233.—Jaekel, Zeitschr. d. Deutsch. geol. Gesell. for 1897 [1898], p. 45.—Bather, Treatise on Zoology (Lankester), pt. 3, 1900, p. 189.—Springer, Amer. Geologist, XXX, 1902, p. 95; Jour. Geology, XIV, 1906, p. 518.—Zittel-Eastman, Textbook Paleontology, 1913, p. 205.

*Dimerocrinites,* Pacht (not Phillips), Verhandl. K. Russ. Min. Gesell., 1853, p. 339 (Separate 1852, p. 8).

*Zeacrinus* (Troost), Schultze (not Hall), Mon. Echinodermen Eifler Kalkes, 1867, p. 38.—Dewalque in Fraipont, Ann. Soc. Geol. Belgique, XI, 1884, p. 112.

*Aristocrinus* Rowley, Amer. Geologist, XVI, 1895, p. 217.

*Callawaycrinus* Rowley, Amer. Geologist, XVI, 1895, p. 219.

Not *Dactylocrinus* Sladen, Proc. Geol. and Polyt. Soc. West Riding, Yorkshire, 1878 (The genus *Poteriocrinus* and allied forms), p. 4.

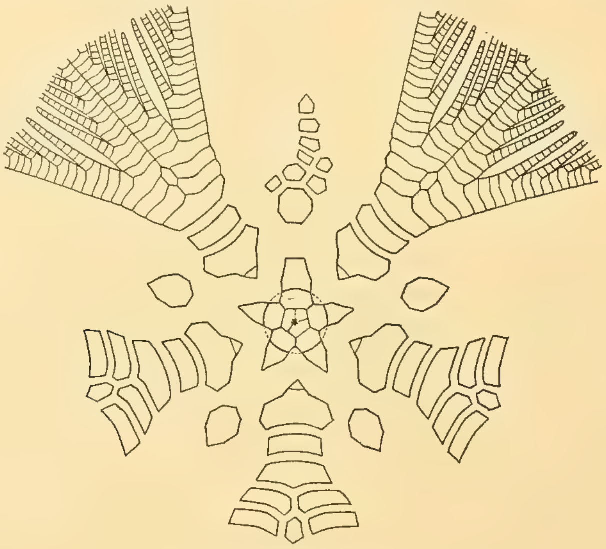

Fig. 40. *Dactylocrinus*

Ichthyocrinidae with rays above radials separated in lower part. Crown elongate to rotund, spreading from radials up. Infrabasals entirely within ring of basals. Posterior basal elongate. Radianal not identifiable. Anal *x* followed by smaller plates in one or more series. Interbrachials few; areas narrow, with rays meeting above them but not interlocking. Primibrachs two. Arms heterotomous; rays in twenty main trunks with ramules on inside of dichotom, usually simple. Column large, enlarging proximally.

*Genotype. Dimerocrinites oligoptilus* Pacht.

*Distribution.* Devonian and base of Lower Carboniferous; Russia, Germany, Belgium, and the United States.

This genus marks the introduction of the heterotomous arm, so far as we know, in the family Ichthyocrinidae. In most of the species it is a very regular mode of branching, with symmetrical ramules, small, close together and gradually diminishing, being but a short step from pinnulation although only unilateral. The shortest intervals are in *D. beyrichi* from the Rhineland Devonian, in which the ramules are borne on every second brachial, that is with intervals of one; the less characteristic species, *D. alpena* and *D. tardus,* have intervals of 4 and 5. In these two species the heterotomy is of an intermediate character, the ramules becoming enlarged to more nearly the size of the main arm trunks; the last named is the latest survivor of the genus. If the mode of arm branching were to be taken as of controlling weight in the arrangement of families, *Dactylocrinus* and its heterotomous allies would all be placed in one family, as Bather has done. This arm structure seems to me a subordinate modification which is repeated independently in several well-defined families of both the other orders of the Crinoidea, viz., Dimerocrinidae, Melocrinidae, Actinocrinidae, Platycrinidae and Hexacrinidae of the Camerata, and Cyathocrinidae of the Inadunata. According to my view, a parallel modification occurs in most of the families of the Flexibilia, although without any correlation as to geological succession.

In the basal structure the characteristic of the family is strongly marked, with a tendency of the infrabasals to retreat still further from participation in the calyx wall into a greater concavity; this reaches the extreme in *D. excavatus,* where they are buried at the bottom of a deep excavation involving the basals and part of the radials, and filled by the column for a considerable distance (Pl. XLI, fig. 5*d*). The form and proportions of the basals are remarkably constant in the genus and constitute one of the best characters for recognizing it; they usually project from the concavity in more or less long, narrow tongues, but in every case the posterior basal rises high above the rest to nearly or quite the upper margin of the radials.

In superficial appearance the resemblance between *Dactylocrinus* and *Synerocrinus* is very strong, but the difference in the construction of the anal area is decisive; that of *Synerocrinus* being a single vertical series of plates soon to become a tube bordered by perisome, while in *Dactylocrinus* the anal plates are in more than one series, filling the lower part of the area by sutural union with the brachials; and the anal *x,* instead of being a quadrangular plate, is angular above, supporting two or more plates. The difference noted by Bather (Lankester's Zoology, pt. 3, p. 190), that in *Dactylocrinus* the proximal ramule branches again seems not to be very reliable. In Pacht's description and figure of *D. oligoptilus* this appears to be so at only one place, whereas the nineteen other proximal ramules are of a simple type. In *Synerocrinus* the interbrachial system is more profusely developed, mature individuals having five to eight plates, and even young specimens have more than one; while in *Dactylocrinus* the number is rather constantly limited to one, or sometimes none. The two genera are of widely different geological age, and appear to be closely limited to their respective horizons.

Another genus very similar to this in arm structure is *Wachsmuthicrinus,* which follows it closely in geological succession, and might well be taken as the successor of *Dactylocrinus,* with all anal structures eliminated and to some extent the interbrachials also; the latter are rarely absent in *Dactylocrinus,* but frequently so in *Wachsmuthicrinus.* By some confusion of types the analysis of genera on page 518 of my paper of 1906 (Jour. Geology, vol. 14), was made to state the number of main trunks in both these genera as 10, instead of 20.

For a type so little known in the first instance the literature of the genus is involved in an unusual amount of confusion. It was described by Pacht in 1852, from specimens from the Upper Devonian limestone of the government of Pskov, Russia, under the name *Dimerocrinites oligoptilus,* with very fine and elaborate illustrations. He assigned his new species to Phillips's genus under a complete misapprehension of the characters of the latter, which Phillips had proposed for species which he declared himself to be "unable, at present, to characterize completely." Having the impression from certain remarks of Johannes Müller and Phillips that the much discussed species, *Poteriocrinus nobilis* Phillips and *Cyathocrinites tuberculatus* Miller, did not belong to their respective genera, and recognizing in his own species a certain resemblance to them, Pacht concluded to place all three under the still less understood *Dimerocrinus,* making *P. nobilis* and *C. tuberculatus* synonyms under the name

*Dimerocrinus nobilis* (*op. cit.*, pp. 7-8). His error, therefore, was not in the perception of general systematic relations, in which he showed excellent judgment, but in the misunderstanding of the genus *Dimerocrinus*—a difficulty in which he was not without company, as the synonymy of that genus will demonstrate.

In 1881 and 1885 Wachsmuth and Springer (Rev. Pal., pt. 2, p. 231; pt. 3, p. 144) referred Pacht's species to *Taxocrinus*, a genus which as then understood would include both this form and the somewhat similar "*Taxocrinus*" *thiemei*. In 1886 Wenjukoff[1] described a specimen from Isborsk, northwestern Russia, under Pacht's name, referring it with doubt to *Taxocrinus*.

In 1895 Professor Rowley described and figured a beautiful new species of this type from the Devonian of Missouri, for which he proposed a new name, *Aristocrinus;* to make assurance doubly sure against possible preoccupation of the name, he proposed as an alternative *Callawaycrinus*.[2] He evidently did not intend to include Pacht's species in his genus, since he made no reference to it.

In the meantime Quenstedt (1876, Petref. Deutschland, Bd. 4, Abth. 1, p. 520) discussed the *oligoptilus* of Pacht at some length, showing that it differed essentially from the English species described under *Dimerocrinus;* and he pointed out in detail a character of undoubted generic importance, viz., 20 main arms (Hände) bearing ramules (Nebenärmchen) "which stand in only a single row on the inner side of the hands and are so coördinated like the fingers of *Pentacrinus* that we have here before us a finger-crinoid, *Dactylocrinus*." He said that these ramules were not pinnules, or they would be biserial and alternating. In his later Handbuch der Palaeontologie, 1885, Quenstedt did not mention the genus; but in 1879 Von Zittel (Handb. d. Pal., p. 354) recognized *Dactylocrinus* with a query, credited it to Quenstedt, and gave a good generic diagnosis in conformity with Quenstedt's observations, referring to the type species as *Dimerocrinus oligoptilus* of Pacht; but no further mention of it was made in his subsequent Grundzüge der Palaeontologie.

The generic type being thus recognized and defined under a valid name, the only question is to whom it should be credited—Quenstedt or Von Zittel. Quenstedt did not give a formal diagnosis under his name, but his observations contained a clear indication of the characters on which he considered the species to differ from the genus under which it had been described. We have therefore a published name, an intelligible indication of characters, and a well known type species. This brings the case clearly within the twenty-fifth article of the International Code of Nomenclature, and the genus must date from Quenstedt, 1876.

Rowley described his species originally under *Taxocrinus* (American Geologist, vol. 12, 1893, p. 304) as having twenty stout arms with pinnules. Afterward (*ibid.*, vol. 13, 1894, p. 153) noting the fact that pinnules had not been observed before in any of the Ichthyocrinidae, he said "if what we have designated arms are really free rays, and the so-called pinnulae arms, we have here an aberrant *Onychocrinus* or a new generic form." It was this consideration mainly that led him afterward to propose a new genus, and it is evident that the decisive character on which he relied to separate his species from *Taxocrinus* was that pointed out by Quenstedt as the basis of his *Dactylocrinus*. If he had seen the figures of *D. oligoptilus* in Pacht's paper (which is a very rare publication, found in but few libraries in this country) there is no doubt that he would have perceived the relation of the two species. As it is, his independent recognition of the generic importance of the arm structure disclosed by his specimens was a just and valid observation, and I only regret that under the rules of nomenclature the adoption of his name is precluded by the priority of Quenstedt's action.

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[1] Faune Dev. Syst. Nordw. u. Cent. Russia, p. 31, pl. 1, fig. 11.

[2] American Geologist, vol. 16, pp. 217, 219.

Schultze in 1867 (Mon. Echin. Eifler Kalkes, p. 38) described a species from the Middle Devonian of the Eifel Mountains as *Zeacrinus excavatus,* and a variety as *Z. interscapularis,* which clearly belong to this genus. Wachsmuth and Springer in 1879 (Rev. Pal., pt. 1, p. 50) recognized their relation to the Flexibilia instead of to the Inadunata, but not being then acquainted with Pacht's species or Quenstedt's genus referred them without good reason to *Gnorimocrinus.*

Fraipoint in 1884 (Ann. Soc. Geol. Belgique, vol. 11, p. 112) described under the name *Zeacrinus beyrichi* Dewalque a species of this genus from the Upper Devonian at Senzeille, Belgium, and called attention to the resemblance of his species to the *Zeacrinus interscapularis* and *Z. excavatus* of Schultze, from nearly equivalent strata in the Eifel Mountains; and he suggested that the three species presented characters sufficient to warrant their reference to a new genus.

Neither Pacht, Quenstedt, nor Von Zittel in their descriptions and discussions made any mention of the infrabasals. Fraipoint says they are invisible in his specimen, and Rowley is noncommittal, saying that they are " if present, hidden by the upper stem joint." This is not strange, for these plates lie within a sharply bordered basal depression in which the top stem joint is usually left firmly attached. Schultze found the second circlet of basals in the deeply excavated basal cavity of his species, calling them "cryptobasalia," and erroneously stating their number as five.

*Dactylocrinus* represents a well-defined and vigorous type, with a wide geographical range, having now been recognized from Devonian strata in Russia, Germany, Belgium and America.

All the European species are from the Middle or Upper Devonian; those of the United States are from the Hamilton, except the intermediate or doubtful species *D. tardus* from the Waverly.

The species, six in number, are arranged as follows:

### THE SPECIES OF DACTYLOCRINUS

I. Ramules small, well-differentiated.
  Crown short, rotund, contracting upward.
    Inner arm-trunks smaller than outer.
      Base deeply excavated, involving part of RR and all lower plates.
        Ramules slender, at intervals of 4 to 6.
          iBr present or absent.................................... *D. excavatus.*
      Base broadly concave; BB extending beyond cavity.
        Ramules small, at intervals of about 4.......................... *D. concavus.*
  Crown elongate, spreading upward.
    Main arm trunks about equal.
      Base shallowly concave.
        Ramules slender, at intervals of about 3....................... *D. oligoptilus.*
      Base sharply excavated.
        Ramules stout, at intervals of 1............................... *D. beyrichi.*
II. Ramules large, resembling arm divisions.
  Crown elongate. Base shallowly concave.
    IIBr 3.
      Ramules at intervals of 4 or 5.................................... *D. alpena.*
    IIBr 4 or 5.
      Ramules at intervals of 6 or 7, approaching dichotomy............ *D. tardus.*

### **Dactylocrinus excavatus** (Schultze)

*Plate XLI, figs. 5-6*

*Zeacrinus excavatus* Schultze, Mon. Echinodermen Eifler Kalkes, 1867, p. 39, text-fig. 6, pl. 7, figs. 2, *2a, b.*—Quenstedt, Petref. Deutschlands, IV, 1876, p. 514, pl. 108, fig. 25.

*Zeacrinus excavatus* var. *interscapularis* Schultze, Mon. Echinodermen Eifler Kalkes, 1876, p. 40, pl. 7, figs. 3, 3*a*, *b*.

*Taxocrinus* (*Gnorimocrinus*) *excavatus*, Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 50.

*Dactylocrinus excavatus*, Jaekel, Zeitschr. d. deutsch. geol. Gesell., for 1897 [1898], XLIX, p. 47.—Springer, Jour. Geology, XIV, 1906, p. 515.

A rather small species. Crown relatively short and wide, with very broad base. Height of calyx to width at axillary IIBr, 1 to 1.5; spread of calyx from lowest point of curved radials, 1 to 1.4; cross-section decagonal, side outline nearly straight and perpendicular. Base very broadly truncate, invaginated into a very large deep cavity involving the whole of the basals except the posterior, and a good part of the radials: it is so deep that the infrabasals rest at about the level of the lower IIBr. Surface smooth. Crown, 22 mm. high by 19 mm. wide; height of $IIBr_1$, 13 mm.; base at outer edge of curvature, 13 mm.; inner diameter of basal concavity, 5 mm.; depth, 12 mm.; diameter of column facet at bottom of concavity, 3 mm.

IBB, BB, and lower part of RR all included within basal concavity and invisible in side view, except post. B which rises above distal face of RR; it is succeeded by several anal plates in ranges of two or more abreast filling a triangular area, above which the rays meet. iBr one elongate plate, or may be entirely absent. Rays broad and short, inner ramus smaller than outer. Br diminishing in width by steps from four times as wide as high at IBr to about equal height and width at IIIBr 2 or 3. Intervals wide; first ramule on third to fifth IIIBr, with similar intervals above; ramules small, not over one-third the width of brachial, and probably not over three or four in number. Column not preserved, but from space in basal cavity must have been of moderate size.

The remarkable thing about this species is its extremely deep basal concavity, in which respect there is nothing like it in any other species of the Flexibilia. That which in other species of the genus is a more or less shallow concavity is here a complete invagination, extending to the middle of the radials. It is so large, and rises to such a height in the middle of the calyx, that the space for the viscera is greatly reduced, and must have been compensated by a very high tegmen which is not indicated by the height of the crown as seen in the fossil state; it probably collapsed under contraction of the infolding arms. The curvature for the invagination begins at about half way up the radials, which are recurved and form the rim of the cavity; the points of the regular basals do not appear at its edge, but they extend inward and upward for a distance equal to the height of the radials and primibrachs combined. In figure 5*c* on Plate XLI the cavity is 12 mm. deep, measuring from the level of the rim; and allowing an average thickness for the plates the inner floor of the infrabasals would be at about the level of the top of the first IIBr, or nearly as high as the apex of the triangular anal area.

The relation of these parts is better shown by the cross-section, figure 5*d*. In the other specimen, 6*a, b, c,* the cavity is nearly as deep and relatively wider. The latter has one good-sized interbrachial, as usually found throughout the genus, but 5*a-c,* although a mature specimen, has no semblance of such plates nor space for any—the rays abutting closely on a straight line. These are the only specimens known, so that we do not know which form is the more prevalent in the species; but it is evidently a similar case to that of *Wachsmuthicrinus thiemei,* in which interbrachials are present or absent irrespective of stages of growth. Schultze defined the species upon the specimen without interbrachials, and proposed for the other one the variety *interscapularis;* but in view of the high specialization of the forms in other characters it does not seem advisable to separate them.

In Schultze's diagram of the species (*op. cit.,* p. 39, fig. 6), and his figure of the first specimen (*ibid.,* pl. 7, fig. 2*a*), some large anal plates are erroneously shown; the anal plates in both specimens are mostly gone, and through the space occupied by them may be seen in one place part of the wall of the inward projecting basal cavity. The species has small ramules, and few of them; in its short, non-spreading crown it is closer to *D. concavus* than to any other species.

*Types.* Museum of Comparative Zoology, Harvard College.

*Horizon and locality.* Middle Devonian, Eifel limestone (Stringocephalen-Kalk); Kerpen and Steinfeld, Eifel, Germany.

### **Dactylocrinus concavus** (Rowley)

*Plate XLI, figs. 7-9*

*Taxocrinus concavus* Rowley, Amer. Geologist, XII, 1893, p. 304, pl. 14, fig. 2.—*Ibid.,* XIII, 1894, p. 153, figs. 3, 9, 10 on p. 151.

*Aristocrinus concavus* Rowley, Amer. Geologist, XVI, 1895, p. 217, figs. 1, 2 on p. 220 (? *Callawaycrinus* on p. 219).—Keyes, Bull. Geol. Soc. America, XIII, 1902, p. 285.—Greger, Amer. Jour. Sci., XXVII, May, 1909, p. 376.

A rather small species. Crown short, rotund, with broad base; contracting above IAx, where height to width is 1 to 2.2; spread of calyx from outside of basal rim, 1 to 2; cross-section obtusely pentagonal, side outline curved. Base broadly and shallowly concave, resting on basals and lower incurved points of radials. Surface smooth. Crown of mature specimen, 25 mm. high by 22 mm. wide; base at line of curvature of rim, 11 mm.; column facet, 5 mm.

IBB small, wholly covered by the column. BB curving from basal cavity to outside of rim; their points visible in side view; post. B truncate, not rising to top of RR, followed by small anal *x*, and this by two series of 3 or 4 plates tapering to an apex between posterior rays. iBr one very large plate, rising to top of $IIBr_1$, with a wide, rounded, distal face, probably for attachment of perisome. iIIBr present in large specimens. RR unusually large for the genus—the largest plates in the calyx. IBr much shorter and narrower. Rays and their divisions deeply rounded, tapering but little; the inner branch the smaller; IIBr usually 3, occasionally 2 or 4. Ramules small, 4 to 6 visible below point of infolding; intervals usually of 3 or 4 brachials, shorter in the distal portions. Column small, with thin ossicles next to calyx.

A well-marked and constant species, nearer to *D. excavatus* than to any other, but without its deep basal cavity; otherwise distinguished by its longer, more rounded, and less tapering ray divisions. In that species the ramules become equal to the main branches at about the third division, whereas here they are well differentiated to at least the sixth.

*Types.* The originals of figures 7 and 8 are in the collection of Professor R. R. Rowley, of Louisiana, Missouri; that of figure 9 is in the author's collection.

*Horizon and locality.* Middle Devonian, Hamilton Group, limestone bed at middle of Craghead Creek shale; near Fulton, Callaway County, Missouri, associated with three described species of *Melocrinus*.

## **Dactylocrinus oligoptilus** (Pacht)

*Plate XLI, figs. 1-2*

*Dimerocrinites oligoptilus* Pacht, Beitr. Kenntn. *Dimerocr.*, (Separate) 1852, p. 8, pl. 1, figs. 1-9; pl. 2, figs. 1-12; pl. 3, figs. 1-12 [Verh. K. Russ. Gesell., 1853, p. 339].

*Dimerocrinus oligoptilus,* Eichwald, Lethaea Rossica, I, 1860, p. 597.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 2, 1881, p. 231.

*Dactylocrinus oligoptilus,* Quenstedt, Petref. Deutschlands, IV, 1876, p. 520, pl. 108, fig. 32 (*Dimerocrinus* on plate).—Jaekel, Zeitschr. d. deutsch. geol. Gesell., XLIX, for 1897 [1898], p. 44.

*Dimerocrinus* (*Taxocrinus* ?) *oligoptilus,* Wenjukoff, Fauna Dev. Syst. Nordw. u. Cent. Russ., 1886, Original, pp. 447, 691 (Résumé, p. 31), pl. 1, fig. 11.

*Taxocrinus oligoptilus,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 3, 1886, p. 144.

Type of the genus.

Specimens attaining a large size. Crown elongate, expanding gradually until above the second bifurcation, rays increasing in width above the radials. Height to width at $IIBr_3$, 1 to 1.4; spread of calyx, 1 to 3.2; cross-section at that level decagonal, side outline slightly curved. Base broad, expanding into a slightly rounded rim and then recurving into a shallow concavity, formed by the incurved parts of radials and basals, with the column facet at the bottom. Surface coarsely granulose. Crown of maximum specimen 52 mm. high by 32 wide; base at outside of rim 10 mm.; diameter of column at base 5 mm.

IBB small, entirely covered by proximal columnals at bottom of concavity. BB much elongated, projecting in narrow tongues which curve over the rim of the concavity; post. B much higher, reaching to about the top level of RR, where it is truncate and narrow, partly supporting first anal plate. Anal *x* of moderate size, with three lower faces supported by post. B and short shoulders of RR; it is about the height of the abutting IBr, angular above, followed by a median series of several plates (somewhat disturbed in the type specimen), with some smaller plates at either side, all suturally united to adjacent rays and narrowing to a point as the rays meet above. iBr one large plate, more than twice the size of anal *x*, acute-angled above; iIIBr sometimes present. RR with tongue-like projection curving into the basal concavity between BB; primibrachs half as high as wide, and about the same size as RR, but slightly narrower on account of the interbrachials; above them the rays increase in width rapidly. Rays and their divisions rounded, tapering rapidly; the two rami equal in size, the outer margins of the ramuliferous dichotoms contiguous but not interlocking. IIBr 3, widening upward; IIIBr short and wide, plates diminishing regularly in width by steps as ramules are given off at every third or fourth plate. Ramules very small, rounded, having much the proportions of pinnules; lower ramules less than one-third the width of the plates which bear them, those higher in the ray gradually approaching the size of the main arm. There are ten or more ramules in a mature specimen, usually simple; branching observed exceptionally. Column round, half the diameter of the base outside of the rim; proximal columnals thin, there being at least three within the basal cavity.

Not having access to the types or to any other specimens, I have in the description of this species been compelled to rely entirely upon Pacht's figures. These are very elaborate, and bear evidence of great care and skill in the study of the excellent material before him; so much indeed as to induce regret that he did not propose a generic name for this new and distinct type, instead of referring it to a genus with which it has no possible connection. I have made a slight correction in his cross-section of the base (Pl. XLI, fig. 1*d*), to agree with the present understanding gained from the study of other species; what he represents as the upper columnal projecting inside the base is clearly the infrabasal ring, just as is seen in the section of *Dactylocrinus excavatus* on the same plate. The large central opening at the inside (fig. 1*e*) is the expanded triangular funnel found in other genera. In the small size and regular form of the ramules, this species is an excellent example of the stage of heterotomous arm-branching which is superficially close to pinnulation; the intervals consist of two or three brachials in the lower part, but they become shorter toward the distal end of the arm, a fact also observed in other species.

The species occurs in the lower beds of the Upper Devonian, associated with *Spirifer archaici* and *Rhynchonella cuboides*. The principal type specimen was found at Costijitsi, on the bank of the river Schelon in the government of Pskov, in northwestern Russia. Another used in the illustrations by Pacht was from Isborsk in the same region; and Wenjukoff in 1886 described and figured still another well-preserved specimen from the latter locality, evidently a much younger individual and differing from those of Pacht in having four IIBr, provided the figure is correct; it does not afford details enough to be of service for comparison.

*Types.* I have not been able to locate the types.

*Horizon and locality.* Upper Devonian; Government of Pskov, Russia.

### **Dactylocrinus beyrichi** (Dewalque in Fraipont)

*Plate XLI, figs. 3-4*

*Zeacrinus beyrichi* Dewalque in Fraipont (Recherch. Crin. Famennien Belgique), Ann. Soc. Geol. Belgique, XI, 1884, p. 112 with text-fig., pl. 1, fig. 5.

*Taxocrinus beyrichi,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 3, 1886, p. 144.

*Dactylocrinus beyrichi,* Jaekel, Zeitschr. d. deutsch. geol. Gesell., for 1897 [1898], p. 47.

Specimens of moderate size. Crown elongate, expanding to top of IIBr, where height to width is 1 to 1.7, spread of calyx, 1 to 3.5; cross-section at that level deeply decagonal; side outline slightly curved. Base truncate, more rounded than in *D. oligoptilus* and without any expanded rim; sharply excavate, the edge cutting radials and basals, and the cavity deep enough to hold several columnals. Surface coarsely granulose. Crown of largest specimen, 31 mm. high by 25 mm. wide; base, 7 mm., column, 5 mm.

Other structural details are generally similar to those of *D. oligoptilus,* except that here the ray divisions are more deeply rounded, diverge at a wider angle, and do not taper so decidedly upward. The ramules are stouter, and are given off at shorter intervals, one from every second brachial; about seven are visible before the arms infold, and there were probably ten or more in all. Proximal columnals very thin.

The description is made from a very good specimen from Senzielles, considerably larger than the type (Pl. XLI, figs. 4*a, b*). I have copied Fraipont's type figure, but it is incorrect in representing ramules from every successive brachial; the alternate plates are rather short, and run to a sharp angle between the bases of the ramules; these were overlooked by the artist, but the text, as well as the diagrams on page 112 of Fraipont's paper, shows one ramule for every two plates. I also suspect that the interbrachials are too large in Fraipont's figure; they are relatively wider than they appear in the diagram. The species is nearest to *D. oligoptilus,* being from a closely equivalent horizon; but the rounded base with thin edge of the concavity, and the great difference in the ramules, will serve to distinguish it.

The horizon of this species is the Frasnien limestone, in the lower part of the Upper Devonian. It is associated with *Melocrinus hieroglyphicus* and several other species of the Eifel limestone occurring in the upper beds of the Middle Devonian, or Stringocephalen-Kalk. Specimens are very rare. Those figured are from Senzielles, and I have another fragmentary specimen from Chimay.

*Types.* Fraipont's original was formerly in the collection of Professor G. Dewalque of Liege. The other specimen figured is in the author's collection.

*Horizon and locality.* Lower part of Upper Devonian, Frasnien; Senzielles, near Couvin, and Chimay, southern Belgium.

### **Dactylocrinus alpena** n. sp.

*Plate XLI, figs. 10a, b*

A medium-sized species. Crown elongate, height to width at about the fourth axillary, 1.6 to 1; of calyx at IAx, about 1 to 1.5. Ray divisions about equal, with but little taper; axillary plates wider than those next preceding. Rays and their main divisions in close contact at least as high as the third bifurcation; all brachials from IBr up have a median elevation sloping to the sides, and are flanked by prominent lateral buttresses which interlock at the interbrachial sutures. IIBr 3, exceptionally 4. Ramules five or six in number, at intervals of 4 or 5 brachials; large, resembling the main arm branches, and two-thirds as wide. iBr few, usually 1; small, angular, with rays closely abutting above them. Surface smooth except for the angularities on brachials. Anal structure and base not exactly known. Holotype about 30 mm. high by 18 wide at about the second ramule.

This species is founded upon a single specimen consisting of a complete set of arms, with base broken off; it was found on the beach of Lake Michigan at Alpena somewhat weather-worn, and the rays appear more rounded dorsally than they probably were originally. The arm-branching shows a distinct tendency toward dichotomy, in which it differs from all the preceding species, as well as in the marginal sculpturing of the rays. In the latter feature it much resembles *Synaptocrinus nuntius,* and there is a possibility that the species is an aberrant form of that genus, although the mode of arm branching and the interbrachial structures are against it. The specimen is much flattened, and the anal area distorted by pressure, but relatively to the other areas its proportions are decidedly those of the present genus.

*Types.* Author's collection. Collected by Rev. W. H. Barris, and presented for use in this work.

*Horizon and locality.* Middle Devonian, top layer of the traverse beds of the Hamilton group; Partridge Point, near Alpena, Michigan.

### **Dactylocrinus tardus** (Hall)

*Plate XLI, fig. 11*

*Forbesiocrinus lobatus* var. *tardus* Hall, Prelim. Notice 17th Rep. New York St. Cab. Nat. Hist., 1863, p. 7 (17th Rep., 1864, p. 56).

*Forbesiocrinus tardus* Hall, Hall and Whitfield, Geol. Surv. Ohio, Pal. II, 1875, p. 170, pl. 12, fig. 2.

*Taxocrinus lobatus* var. *tardus,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 49.

A large species. Calyx elongate, spreading upward; with rounded rays and large ramules resembling arm-branches. Surface smooth. Crown about 31 mm. high by 15 mm. wide.

The species is represented by a single imperfect specimen, too much flattened and injured to afford full details of structure. The concave base with IBB and BB hidden by the column, and the long, narrow post. B rising to the height of the radials, proclaim its affinities with the genus. It has the usual anal structure, though the plates are not preserved; and it apparently had no interbrachials. There are 4 or 5 IIBr, and longer intervals between the ramules than in any other species, being 6 or 7 brachials. The outer branches of the ray divisions are slightly the larger, the ramules large, and the arm branching is strongly in the direction of dichotomy. Column large, with very thin ossicles tapering from the calyx.

This is the last known survivor of the genus, being from the lowest member of the Lower Carboniferous, and in its intermediate type of heterotomy it departs most widely from the typical species.

*Type.* New York State Museum, Albany.

*Horizon and locality.* Lower Carboniferous, Waverly Group; Richfield, Cuyahoga County, Ohio.

## **EURYOCRINUS** Phillips

*Plate XL, figs. 1-8*

*Euryocrinus* Phillips, Geology Yorkshire, II, 1836, p. 205.—Goldfuss, Nova Actae Acad. Leop. XIX, 1839, p. 352.—(*Euryocrinites*) Austin and Austin, Ann. and Mag. Nat. Hist., (1) X, 1842, p. 109.—Morris, Cat. British Fossils, 1843, p. 52 (2d Ed., 1854, p. 79).—Bronn, Lethaea Geognostica, I, 1856, p. 22.—Rofe, Geol. Mag., (1) X, 1873, p. 263.—Wachsmuth and Springer, Revision Palaeocrinoidea, I, 1879, p. 33.—Bather, Rep. British Assoc. for 1898 [1899], p. 923; Treatise on Zoology (Lankester), pt. 3, 1900, p. 190.—Springer, Jour. Geology, XIV, 1906, p. 483.—Zittel-Eastman, Textbook Paleontology, 1913, p. 205.

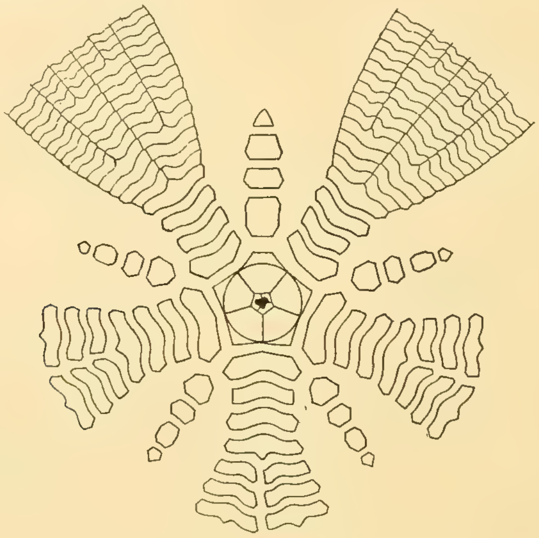

Fig. 41. *Euryocrinus*

Ichthyocrinidae with rays above radials partly separated by solid plates arched over by brachials. Crown expanding upward from radials. Infrabasals entirely within the ring of basals, sometimes resorbed. Posterior basal elongate. No radianal. Anal *x* followed by others mostly in single series, filling the area. Interbrachials few, usually limited to a single series. Primibrachs three. Arms dichotomous, abutting. Column large, expanding toward the calyx.

*Genotype*. *Euryocrinus concavus* Phillips.

*Distribution*. Devonian to Lower Carboniferous; England and the United States.

Considered according to the criteria which I have adopted as controlling in this group, *Euryocrinus* stands structurally nearer to *Amphicrinus* than to any other genus. It has the same compact anal side with mainly a single series of plates, but it lacks the disproportionate and unusual development of plates in the other interbrachial areas; and it has three primibrachs instead of two. The inequality among the basals is not so pronounced as in that genus. In superficial appearance it is close to *Parichthyocrinus*, with which it also agrees in number of primibrachs. The character of the anal interradius, entirely filled by solid plates suturally joined to those of adjacent rays, differentiates *Euryocrinus* on grounds of family importance, which are perfectly clear in normal specimens of *Parichthyocrinus* with its tube-like anal series bordered by a pliant integument. Some variation in the structure in the latter genus tends occasionally to obscure the clearness of this distinction, the anal series appearing nearly to fill the area with little appearance of bordering integument; these cases, however, are evidently sporadic variations in one abundant species.

As in *Ichthyocrinus,* there is in this genus considerable degeneration of the base, with a tendency to resorption of the infrabasals. In the type specimen of *E. concavus* they have almost disappeared externally (Pl. XL, fig. 4*a*), but a small portion at the left side is visible in the interior (fig. 4*b*); and in the type of *E. rofei* (fig. 7*b*) about one-half of the infrabasals, including the entire right posterior small plate, have been resorbed. This condition of the type of *E. concavus* gave rise at one time to the impression that the genus was monocyclic.

The literature relating to *Euryocrinus* is full of confusion, owing partly to the inadequacy of the original description by Phillips (Geology of Yorkshire, vol. 2, 1836, p. 205). His generic and specific description was as follows: "Pelvis opening pentagonal, arrangement of plates like *Encrinus;* internal cavity very large." This allusion to *Encrinus* led the Austins, and after them Bronn in his Lethaea Geognostica, 1856, to class it with the Encrinoidea or Encrinidae; while the appearance of the interbrachial plates shown by Phillips's figures induced Bronn afterwards in his Klassen und Ordungen des Thierreichs, 1860, to place it as a synonym under *Actinocrinus,* in which he was followed by Von Zittel in Handbuch der Palaeontologie, 1879. The fact that the peculiar structure and characters of the Flexibilia were not then understood may account for much of this early misconception of the relations of this form; for Phillips's figures, although not quite perfect, were good enough to indicate clearly the systematic position of the genus, as was pointed out by Wachsmuth and Springer in 1879 (Rev. Pal., pt. 1, p. 34), who thought it possibly identical with *Ichthyocrinus,* which at that time was supposed to include species with and without interbrachials.

In the meantime Rofe[1] figured and described under the type species a specimen from another locality (Pl. XL, fig. 7*b*), upon which he based a more detailed description in the terminology of De Koninck, showing two important facts, viz.: (1) a tripartite base and five "subradials"; (2) the overlapping of the distal face of the radials and lower brachials by the succeeding plates. These structures he described more accurately than some of his predecessors had done, thus indicating clearly the dicyclic base and loose articulation of the Flexibilia. Rofe did not make any suggestion as to the systematic place of this form, but from two allusions in his paper to features in which it was thought similar to *Actinocrinus,* it may be inferred that he considered its affinities to be with that genus.

In 1888 Bather and Gregory, having before them the types of both Phillips's and Rofe's descriptions, proposed to refer Rofe's specimens to a new species, *E. rofei,* but their description was never published; and when in 1905 I had the opportunity to examine the type specimens in the British Museum, Dr. Bather very generously placed their notes at my disposal, and I have pleasure in publishing the species under their names. In 1906,[2] as a result of the examination of the original material, I indicated the definite position of this form as a valid genus.

*Euryocrinus,* so long ignored and misunderstood, and hitherto represented only by the four figured types from the English Lower Carboniferous, proves to have a wide range, both geographic and stratigraphic. It has now been recognized in America by well-defined species both from the Devonian and Carboniferous. The former occurrence is interesting as adding another to the number of Carboniferous genera originating in the Devonian, but the latter is still more so for its importance in relation to the stratigraphy. It has not been found among the prolific faunas of the Keokuk and other later formations, but only in the Knobstone, near the base of the Lower Carboniferous, at a horizon strictly equivalent to that in which the English species occur. The English specimens have been described under three species; being very imperfect, with nothing above the first secundibrachs preserved, the definition of the species is not so close as could be wished. The later discoveries have increased the number of species to five, which may be characterized as follows:

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[1] Geological Magazine, vol. 10, 1873, p. 263, pl. 11, figs. 11, 11*a*, *b*.

[2] Journal of Geology, vol. 14, p. 483.

### THE SPECIES OF EURYOCRINUS

I. Surface smooth or finely granulose.
Calyx elongate, with straight sides.
Radial series with median elevation.
IBB large, but within column facet.
BB visible as elongate triangles.................................*E. barrisi.*
Calyx broadly spreading.
Radial series broadly convex.
Base rather small and narrow.
IBB very small or atrophied.
BB extending little or not at all beyond column.
iBr small and narrow, limited to 1 or 2 ranges..............*E. concavus.*
iBr large ..........................................*E. tennesseensis.*
Base broad.
iBr large, in several ranges of wide plates...................*E. rofei.*
II. Surface tubercular.
Base large.
BB extending well beyond column.........................*E. granulosus.*

### **Euryocrinus barrisi** n. sp.

*Plate XL, figs. 1-3*

A large species, with elongate crown; broadly truncate and excavate at the base; height, 50 mm.; width at IIIBr, 24 mm.; base, 10 mm. Calyx with nearly straight sides, spreading from outside of basal rim to top of IAx, 1 to 1.5. Cross-section at first bifurcation sharply pentagonal. Arms closely abutting to third axillary, with a more or less angular median elevation, and raised winged buttresses at sides of brachials; they are broad below, tapering rapidly with rather short divisions to four bifurcations, beyond which they are more rounded and divergent. Sutures arcuate. Base broadly and shallowly concave. iBr few, spaces narrow with the rays meeting above them. Surface smooth, except for the angularities and marginal elevation of the brachials.

IBB rather large for this family, but entirely within BB, and not filling the column facet. BB large, forming the greater part of the basal rim, and visible in side view as good-sized elongate triangles; post. B narrow and very elongate, nearly as high as RR, followed by one anal plate with a few others succeeding in one principal series and some smaller plates at the side. iBr 1, moderately large, angular, with one or two smaller ones following in large specimens; arched over by the wing-like projection of the axillaries; iIIBr sometimes present. RR large, wider than succeeding IBr, their lower angles curving into the basal cavity. IBr 3, short and wide, increasing in width to the axillaries. IIBr 3; IIIBr 4 or 5 inner, and 8 or 10 outer; plates of these series as well as the upper two IBr very short and wide, meeting and interlocking laterally by angular margins, with a prominent node or ridge at the angles. All higher brachials very short and wide. Column large, with excavate facet less than diameter of basal rim; tapering slowly from the calyx and gradually changing from short to longer and alternating columnals.

This species is represented by two well-preserved calices from the Hamilton group at Alpena, Michigan, and a nearly complete specimen with stem and arms from equivalent strata at New Buffalo, Iowa. The latter is considerably flattened, so that the calyx appears wider and more robust than in the others; it is somewhat weatherworn in the lower part, where the sharp angularity of the rays does not appear, but the sculpturing of the brachials from the first axillary up is finely shown. The smaller calyx, cleaned from the soft limestone matrix, has this angularity well preserved in the lower part. The two calices also show very prominently the nodose projections at the margin of the brachials, so that in this respect we have the structures completely represented. There can be no doubt as to the propriety of referring these specimens to the rare genus *Euryocrinus,* with which they agree in all essential structures, the anal side differing only in minor detail. The species differs from those of the Carboniferous in its more elongate and less curved form, larger basals, and the sculpturing upon the brachials.

*Types.* Author's collection.

*Horizon and locality.* Middle Devonian, Hamilton Group. The two calices are from the top layers of the Traverse Group of the Hamilton at Partridge Point, near Alpena, Michigan, where they were found by my venerated friend, the Reverend Dr. W. H. Barris, who presented them to me a short time before his death as a contribution toward the present work, and to whose memory I have dedicated the species. The more complete specimen is from the same horizon at New Buffalo, Iowa. No others have appeared in the large collections since made from the Michigan region.

### **Euryocrinus concavus** Phillips

*Plate XL, figs. 4-5*

*Euryocrinus concavus* Phillips, Geology Yorkshire, II, 1836, p. 205, pl. 4, figs. 14, 15.—Austin and Austin, Ann. and Mag. Nat. Hist. (1) X, p. 109.—Morris, Cat. British Fossils, Ed. 1, 1843, p. 52 (2d Ed., 1854, p. 79).—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 34.

*Actinocrinus concavus,* D'Orbigny, Prodr. Pal. Stratigraphique, I, 1849, p. 156.

Not *Euryocrinus concavus,* Rofe, Geol. Mag. (1), X, 1873, p. 263, pl. 11, figs. 11, *11a, b.*

Type of the genus.

Of rather small size. Calyx low, broadly expanding to $IIBr_2$, where height to width is 1 to 2.5; spread of calyx from base to IAx, 1 to 3. Plates smooth or granulose; sutures sinuous, with tendency to imbrication. Crown above $IIBr_2$, and column, unknown. Width of a specimen at IAx, 30 mm.; base, 10 mm.

IBB small, entirely within BB, and tending to become resorbed. BB small, mostly covered by the column; post. B projecting beyond it. Anal series broad, with rays arching over at about the third or fourth plate; iBr 1, exceptionally 2; extremely narrow, and scarcely rising above level of IAx; no iIIBr. Posterior radials smaller than the others. IBr 3, increasing in width strongly from radials up. Column facet large, involving BB and small part of RR.

The extreme narrowness of the interbrachials is a striking feature of this species, being equally pronounced in both type specimens. The infrabasals are only exposed in one specimen, and there they are almost entirely resorbed. The base of the principal specimen is partly covered by a fragment of the upper stem ossicle, which conceals the unresorbed part of the infrabasals and two of the basals (Pl. XL, fig. 4*a*). This fact led to the supposition that the genus was entirely exceptional for this group in being monocyclic and having but four basals. The concealed part of the infrabasals can be seen from the interior, clearly enough in the specimen but dimly in figure 4*b*, and it is plain that they are in the same condition as in *E. rofei* (fig. 7*b*).

*Types.* In the British Museum, Nos. E6983 and E6984.

*Horizon and locality.* Lower Carboniferous, Mountain limestone; Bolland, Yorkshire, England.

### **Euryocrinus tennesseensis** n. sp.

*Plate XL, figs. 6a-c*

A medium-sized species. Crown short, low, and broadly spreading; height about equal to width at lower IIIBr. Calyx low and broad, height to width at top of IAx, about 1 to 3.4; spread from base, 1 to 2.1; side outline convex. Arms broadly convex to the third axillary and in close contact, margins nearly straight and not raised; all brachials very short and wide; sutures arcuate; iBr few, large. Surface finely pustulose. Dimensions of type: Crown, 32 mm. high by about 32 wide; base, 8 mm.; calyx to top of IAx, 5 mm. high by 17 wide.

IBB within BB, covered by column. BB almost entirely within shallow column facet, only very low obtuse points appearing beyond the column. Post. B very large, rising higher than R. RR and IBr short, about three times as wide as long. IIBr 3; IIIBr 4 or 5 inner, 7 or 8 outer, with another bifurcation on the outer ramus at about the 9th plate, after which the arms infold. Anals in single series of 3 or 4 plates; iBr 1 large, followed by 1 or 2 small ones, with a small iIIBr sometimes present; brachials in close contact above all iBr. Column large, with very thin proximal columnals, tapering from the calyx.

This species is interesting as marking the occurrence of this rare genus in the American equivalent of the English Lower Carboniferous to which it belongs, and it adds one more important fact in confirmation of the correlation of the formations at the base of our Lower Carboniferous with the crinoid-bearing Mountain limestone of England and Belgium. It has been found in several localities, mostly in imperfect fragments. The type, from the lower beds at White's Creek Springs, Tennessee, is considerably flattened and distorted, but clearly shows all the essential characters. Owing to this flattening the arms appear less convex than in most of the specimens. Comparison with the English species can only be made as to the calyx; the differences are not great, being chiefly in the interbrachial plates which are here decidedly larger and a more definite feature of the calyx wall than in *E. concavus,* while much more restricted vertically than in *E. rofei.* The pustulose surface, in which this form may somewhat resemble *E. granulosus,* is scarcely more than a fine granulation; and it lacks the large basals of that species.

*Type.* Author's collection, associated with several fragments from the different localities.

*Horizon and locality.* Lower part of the Lower Carboniferous, in the Knobstone shales and limestones called the New Providence beds, equivalent to some part of the Lower Burlington—Choteau—Kinderhook—Waverly beds of their respective localities; White's Creek Springs and Ridge Top, Tennessee; Button Mould Knob, Kentucky; and Knobs in Clark and Washington counties, Indiana.

### **Euryocrinus rofei** Bather and Gregory MS.

*Plate XL, figs. 7a, b*

*Euryocrinus concavus* Rofe (not Phillips), Geol. Mag., (1) X, 1873, p. 263, pl. 11, figs. 11, 11*a*, *b*.

Larger than *E. concavus*. Calyx relatively narrower and with straighter sides. Height to width at $IIBr_1$, 14 to 33 mm.; base, 14 mm. Plates smooth, with sinuous sutures showing no sign of imbrication. Base broad and flat. IBB mostly resorbed. BB and anal series about as in *E. concavus*, but iBr much larger and wider, being about the same as the anals, and extending higher up. On account of this and the width of the base the increase in width of the three primibrachs is much less. Superior parts and column unknown.

This is the form figured and described by Rofe as *E. concavus*. He only gave a side view of the specimen, with two explanatory figures to show the curved sutures and the overlapping of one brachial over the edge of the one below it (patelloid processes of subsequent literature), which strongly attracted his attention. There is another fragment of this species in the British Museum, No. E642, showing only the interior, which has the same tendency to resorption of the infrabasals accompanied by the enlarged growth of the axial canal. The great difference in size and extent of the interbrachials, and the less spreading calyx, distinguish this species from the type.

*Type*. British Museum, No. E7423.

*Horizon and locality*. Lower Carboniferous, Mountain limestone; Clitheroe, England.

### (?) **Euryocrinus granulosus** (Phillips)

*Plate XL, fig. 8*

*Poteriocrinus granulosus* Phillips, Geology Yorkshire, II, 1836, p. 205, pl. 4, fig. 4 (not figs. 2, 8, 9, 10). *Poteriocrinus granulatus* in explanation of plate on p. 246.—Morris, Cat. Brit. Foss., 2d Ed., 1854, p. 87.

*Taxocrinus granulosus*, Morris, Cat. Brit. Foss., 1st Ed., 1843, p. 59.—Bronn, Index Palaeontologicus, I, 1848, p. 1217.

Phillips figured under the above name two entirely different types, his figures 2, 8, 9 and 10 representing Poteriocrinoids with a radianal; and of these, figure 2, was referred to *Poteriocrinus* by De Koninck and Le Hon under the name *Poteriocrinus phillipsianus*. The references of this species by various subsequent authors to *Zeacrinus* and *Hydreionocrinus* were based wholly on figures 2 and 8, and are therefore omitted from the synonymy. The remaining specimen, original of Phillips's figure 4, belongs to this family, perhaps to this genus, although my guess would be rather in favor of *Amphicrinus;* it is a fragment in which only the base and some of the radials are preserved. Both basals and infrabasals are larger than in the other species, the former extending well beyond the column and the latter not being at all resorbed. The surface is distinctly marked with small tubercles. No other specimens of this form have been found.

*Type*. British Museum, No. E6982.

*Horizon and locality*. Lower Carboniferous, Mountain limestone(?); Bolland, Yorkshire, England.

## **METICHTHYOCRINUS** Springer

*Plate XXXIX*

*Metichthyocrinus* Springer, Jour. Geology, XIV, 1906, p. 479.—Zittel-Eastman, Textbook Paleontology, 1913, p. 205.

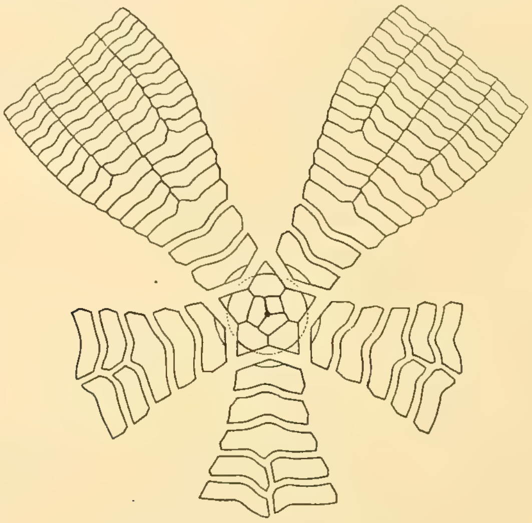

FIG. 42. *Metichthyocrinus*

Ichthyocrinidae with rays in contact all around. Crown globose to ovoid, expanding distally from radials. Infrabasals entirely within ring of basals. Posterior basal not differentiated. No radianal, anal or interbrachial plates. Primibrachs two. Rays widening from radials up. Arms dichotomous, interlocking, in form of mere extensions of the ray divisions. Column with proximal enlargement.

*Genotype. Cyathocrinites tiaraeformis* Troost.

*Distribution.* Lower part of Lower Carboniferous; United States.

*Metichthyocrinus* is the Carboniferous representative of *Ichthyocrinus,* with the radianal eliminated. Along with this modification are some minor changes, such as in the shape of the crown which has become relatively shorter and more rotund; and in the bifurcation of the arms, which apparently end with a large number of tertibrachs, in place of further branching to small finials as in the Silurian genus. Notwithstanding the rotundity of the crown the expansion begins with the radials, the rays regularly widening from the base up, and being thus entirely different structurally from those of the *Lecanocrinus* group. With the increase in convexity of the crown there is seen an occasional occurrence of small, sporadic interbrachials which break through and come to the surface (Pl. XXXIX, figs. 9*a, b*); these do not in any way separate the rays, which close in together above them, and they appear irregularly, having been seen only in a few rays of specimens of *M. burlingtonensis* and *M. clarkensis.*

The infrabasals and basals take no material part in the calyx, the former being within the basal ring, and the latter mostly covered by the column. The axial canal, which is not large, enters with an obtusely pentagonal section, enlarges into a small cavity within the infrabasal ring, where it takes the form of a three-lobed funnel, with a little projecting lip at each angle opposite the middle of an infrabasal. The infrabasal and basal plates are considerably larger externally than on the inner floor of the calyx. This feature is well illustrated by figures 11*c, d,* of Plate XXXIX, which are exterior and interior views of the same specimen, and by figure 12, a vertical section showing the dorso-ventral course of the sutures of the various plates from infrabasals up. The arcuate sutures are very conspicuous in all the species, especially those from the Knobstone, in which they have the appearance of imbrication so prominent in some *Ichthyocrinus.*

*Metichthyocrinus* is a rare genus, with a very limited stratigraphic range; but few species are known, and it has thus far been confined to the Kinderhook, Knobstone and Burlington formations. This statement is in apparent conflict with the record as to the horizon of certain species. *M. clarkensis,* from Clark County, Indiana, is stated by the authors to be from the Keokuk or Warsaw. The type specimen was purchased by Mr. Gurley from a dealer, as were many of Miller and Gurley's types, and there is no authentic record of its exact locality. It is supposed to have been found near Henryville, where the fossiliferous exposures belong to the Knobstone group, which is the source of all other known specimens. The type of Troost's *M. tiaraeformis* is from White's Creek Springs, Tennessee, and is also credited to the Keokuk; but from the appearance of this and some other specimens of the same species found at that locality, and from its known occurrence in some of the Knobs south of Louisville, Kentucky, there is no doubt that it comes from the lower beds at White's Creek, and is therefore from the Knobstone, or New Providence shale, approximately equivalent to the Lower Burlington (see Proc. U. S. Nat. Mus., vol. 41, 1911, pp. 175-208). No trace of the genus has been found at any of the typical Keokuk localities, and no authentic specimen in the Upper Burlington.

The points of differentiation of the species in this genus are few, and are mostly such as might shade into one another by easy transitions among forms prolific in individuals. The general form and proportions of the crown count for something, and the number of secundibrachs, relative breadth of base, and imbrication of the plates, are useful characters. I have arranged the species as follows:

## THE SPECIES OF METICHTHYOCRINUS

I. IIBr usually 3; plates not imbricated.
  Crown ovoid, elongate........................................*M. burlingtonensis.*
II. IIBr usually 4; plates more or less imbricated.
  Crown ovoid, elongate........................................*M. clarkensis.*
  Crown globose.
    Base broad........................................*M. tiaraeformis.*

### **Metichthyocrinus burlingtonensis** (Hall)

*Plate XXXIX, figs. 1-7*

*Ichthyocrinus burlingtonensis* Hall, Geology, Iowa, I, pt. 2, 1858, p. 557, text-fig. 75.—Quenstedt, Petref. Deutschlands, IV, 1876, p. 515, pl. 108, fig. 24.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 34.—Whitfield, Mem. Amer. Mus. Nat. Hist., I, 1893, p. 35, pl. 3, fig. 24.—Keyes, Geol. Surv. Missouri, IV, 1894, p. 223.

*Metichthyocrinus burlingtonensis,* Springer, Jour. Geology, XIV, 1906, pl. 6, fig. 15.

A small species. Crown ovoid, higher than wide, greatest width about IIIBr$_2$; height to width at IIBr$_3$, 1 to 1.6; at IAx, 1 to 2.4; spread of calyx from column to IIBr$_3$, 1 to 4; cross-section circular; side outline convex. Surface smooth. Maximum crown, 22 mm. high by 19 mm. wide; average of 5 specimens, 18 mm. high by 17 mm. wide.

IBB small, limited to the column facet. BB small, usually visible as small triangles beyond the column. RR but little involved in column facet. IBr$_1$ and corresponding higher brachials about 1 to 2.4 in height to width. IIBr usually 3, sometimes 4. IIIBr 10 to 15 or more. Rays evenly curved, without angularity or median ridge; interlocking to at least the upper IIBr, above that abutting, infolding, and tapering rapidly from about the third IIIBr, apparently without further bifurcation. Column facet large, indented. Column large, round, slightly enlarged at the top; composed near the calyx of very short columnals which change somewhat abruptly to ossicles of four times their length alternating with very short ones.

This was the first Carboniferous *Ichthyocrinus* described, although in connection with it Hall in a note gave a description and diagram of Troost's unpublished species, *I. tiaraeformis.* He had only a fragmentary specimen, in which the rays were not preserved beyond the first axillary plate. Neither did it show the infrabasals, which were not mentioned in the description nor in the generic formula, although in his redescription of *I. laevis* from the Silurian Hall had called attention to them as "three small, undeveloped plates." As usually found, the top columnal remains attached in the sharply indented column facet and conceals these plates from view; in one specimen (Pl. XXXIX, fig. 5*b*) they are of fair size externally, but the interior view in another specimen a little larger than this (6*b*) shows how they diminish in size at the inner side of the calyx.

In another interesting specimen (fig. 7) we have an actual vertical section of the crown through the axial canal, showing the calyx wall and the relative positions of infrabasals and basals; it also shows the probable position of the tegmen, though not its structure. The transverse line from the margin of the axillary primibrach represents the upper surface of a very definite granular structure, entirely replaced by crystallized calcite, but wholly distinct from the objects above it which are a mixture of matrix and displaced ends of arms; the integument is doubtless somewhat sunken from its original level, which may have been at the height of the third secundibrach.

The shape of the crown in this species is an elongate ovoid with the widest end up. In this respect it is similar to *M. clarkensis,* but is well distinguished from *M. tiaraeformis.* The same thing may be said as to most of the other characters, except the number of secundibrachs, which in this species is generally 3, and in the others 4. In five specimens of *M. burlingtonensis* preserving the rays these plates appear as follows: Out of 43 rami in which they can be seen, 41 have three IIBr, 1 has four, and 1 has five. In one exceptional specimen 7 out of 10 rami have four.

The number of tertibrachs runs from at least 10 to 15 or more, with apparently no further bifurcation; the arms appear to taper to a rather blunt point, without any indication of such coiling as is observed in the Silurian forms. This extension of the tertibrachs obtains also in *M. clarkensis* and *M. tiaraeformis,* where the number ranges a little higher, being rarely less than 13, while the contrast with the Silurian forms of the family is very marked, they having usually from 7 to 10 tertibrachs with one or more bifurcations following. In conformity with the slightly more elongate form, the brachials in this species and *M. clarkensis* are proportionally a little longer than in *M. tiaraeformis,* the height to width being 1 to 2.4, as against 1 to 3 in that species. Whether there are any differences in the column cannot be ascertained, as it is only known in this species, where it shows somewhat irregular features in two specimens. The enlargement at the top is not very prominent, indeed in one specimen it seems not to be present at all.

Although this is the best represented species of the genus, specimens of it are extremely rare, not over a dozen having been found in all the collections made at Burlington. It occurs in the Lower Burlington limestone, and has not been found, beyond a single doubtful fragment, in the upper bed of that formation. Fragmentary specimens perhaps of this species have been found in the Fern Glen horizon (Kinderhook) Missouri.

*Type.* The specimen used by Hall in his description and which was figured by Whitfield in Mem. American Museum, volume 1, plate 3, figure 24, is in the American Museum, New York. The specimens figured here are in the author's collection.

*Horizon and locality.* Lower Carboniferous, Kinderhook and Burlington; Burlington, Iowa and Fern Glen, Missouri.

### **Metichthyocrinus clarkensis** (Miller and Gurley)

*Plate XXXIX, figs. 8-18*

*Ichthyocrinus clarkensis* Miller and Gurley, Bull. 5, Illinois St. Mus., 1894, p. 43, pl. 4, fig. 5.—Beede, 30th Rep. Geol. and Nat. Hist. Indiana, 1906, p. 1257, pl. 14, fig. 4.

A large species. Crown elongate ovoid, higher than wide, greatest width about IIIBr$_2$; height to width at IIBr$_4$, 1 to 1.6; at IAx, 1 to 2.1; spread of calyx from column to IIBr$_4$, 1 to 4; to IAx, 1 to 2.7; cross-section circular at IIBr$_3$, but above that obtusely decagonal owing to the convexity of the arms and depression of the interbrachial sutures; side outline convex; surface smooth, plates strongly imbricated. Maximum crown, 33 mm. high by 28 mm. wide.

IBB minute, not over half the diameter of column facet. BB small, visible, if at all, only as small points beyond the column. RR partly resting on column. IBr$_1$ and corresponding brachial of higher series about 1 to 2.4 in height to width. IIBr generally 4. IIIBr 13 to 17 or more, transversely convex. Arms well rounded, closely abutting, tapering but little before infolding, and without further visible bifurcation. Column facet indented, including IBB, most or all of BB and part of RR. Column unknown.

In addition to its larger size, and usually greater number of secundibrachs, this species is distinguished from *M. burlingtonensis* by the greater roundness of the arms and less delicate construction. In that species there is almost no convexity of the plates or depression at the interbrachial sutures, and the sutures throughout are marked by light, delicate lines;

whereas in this the plates are well-rounded, their curvature breaking the otherwise circular outline of the cross-section, and the sutures are marked by a strong marginal elevation giving a sharply imbricated appearance. The arms are heavy, abut very closely, and taper but little to the point where they disappear by infolding. The last two features are shared by *M. tiaraeformis,* which also has 4 secundibrachs as a rule. The interlocking of the rays is very perfect at least as far as the upper secundibrach, and there is to be seen at about this level, in at least six interbrachii of the principal specimen, a very small intercalated plate, which probably indicates the vertical limit of the calyx (Pl. XXXIX, figs. 9*a, b*).

*M. clarkensis* was described from a much flattened and imperfect specimen, and from the description and figure I supposed it to be a synonym of *M. tiaraeformis* of the same horizon. Fortunately I came into possession of some excellent material from the same vicinity, which shows that the species may perhaps be maintained. The rather slight difference in absolute dimensions produces a distinct change in habitus which seems to be constant in the specimens. The elongate ovoid outline, relatively narrow base, and more rapid spread of the calyx wall, are plainly shown by the outline restoration of the principal specimen, which although perfect is somewhat flattened (Pl. XXXIX, fig. 9*c*). The basals are not visible in this specimen, and were probably smaller as a rule than in the other species. One fragmentary specimen of this species, not figured, has 3 primibrachs in one ray.

Good specimens of this species are very rare, those figured being all that are known except a few fragments. Several imperfect specimens have been obtained from Button Mould Knob and other localities near Louisville, which furnish useful information as to the structure of the calyx; some of them have a considerably greater development of basals than is considered characteristic, and in this respect show variation toward *M. burlingtonensis* which is from substantially the same horizon (figs. 14-16). One of these specimens (figs. 11*a-d*) is of interest because it shows both the exterior and interior of the base, and gives an excellent idea of the relative proportions and development of these parts.

As in *Ichthyocrinus,* the axial canal, which is obtusely pentagonal below, opens out on the inside into a three-cornered funnel with a projecting rim, following the median line of the infrabasals; this structure at the interior is very well shown by the enlarged figure 11*c*. This interesting specimen, and also the beautiful original of figures 9*a, b,* were given to me some years ago by the Rev. H. Hertzer, of Marietta, Ohio, who collected them at the Knob south of Louisville, Kentucky. Another instructive specimen from the same region gives a vertical section of these structures, obtained by parting at the suture lines, not by grinding (fig. 12); the proximal columnal is in place, and the axial canal is seen passing through it and the infrabasals, enlarging above into the chambered organ. In none of these specimens showing the interior can I find any trace of grooves for the lodgment of the axial nerve cords after they pass upward beyond the triangular funnel within the infrabasals; their course was probably entirely separate from the calcareous substance of the plates.

*Types.* Miller and Gurley's original is in the University of Chicago; the other specimens figured are in my collection.

*Horizon and locality.* Lower Carboniferous, New Providence shales (Knobstone); Clark County, Indiana; Knobs near Louisville, and Bradfordville, Kentucky; White's Creek, Tennessee.

### **Metichthyocrinus tiaraeformis** (Troost) Hall

*Plate XXXIX, figs. 19-21*

*Cyathocrinus tiariformis* Troost, Amer. Jour. Sci., (2) VIII, 1849, p. 420, n. n.; Miller, N. A. Geol. and Palaeontology, 1889, p. 256; Troost (tiaraeformis) Proc. Amer. Assoc. Adv. Sci., 1850, p. 61, n. n.

*Ichthyocrinus tiaraeformis* (Troost) in Hall, Geology Iowa, I, pt. 2, 1858, p. 558, text-fig. 74.—Shumard, Trans. Acad. Sci. St. Louis, II, 1866, p. 378.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 35.—Wood, Bull. 64, U. S. Nat. Museum, 1909, p. 99, pl. 7, figs. 15-17.

*Metichthyocrinus tiaraeformis*, Springer, Jour. Geology, XIV, 1906, p. 477.

A large species. Crown globose, wider than high, very broadly truncate at the base; greatest width about IIIBr$_1$; height to width at IIBr$_4$, 1 to 2; at IAx, 1 to 3.7; spread of calyx from column to IIBr$_4$, 1 to 3.4; to IAx, 1 to 2.4; cross-section at IIBr$_3$ circular, above obtusely decangular; side outline convex. Surface smooth, plates strongly imbricated. Maximum crown, 30 mm. high by 32 mm. wide.

IBB minute. BB small, usually wholly within the column facet, which also involves part of RR. IBr$_1$ and corresponding higher brachials about three times wider than high. IIBr 4, exceptionally 3; IIIBr 14 to 16, no further bifurcations visible. Brachials evenly curved below, becoming convex about the second bifurcation. Arms broadly rounded, closely abutting, and infolding. Column facet indented, and very large. Column with short proximal columnals.

The main character that distinguishes this species from *M. clarkensis* is its globose form, with broad base, very low and broadly spreading calyx, and relatively shorter and wider brachials. The two forms are found at the same horizon, though not certainly at the same localities except at White's Creek. There seems to be a fair degree of constancy in the differences, slight though they are, and in a form with so few structural features apparent in the fossil which can be used for specific determination we must take them for what they are worth. From the type locality we have several good specimens, although the species is quite rare.

The first is the type, in the original collection of Troost now belonging to the U. S. National Museum; it is absolutely rotund and perfect in every particular, lacking, of course, the stem (Pl. XXXIX, figs. 19*a-c*). It has three primary brachials above the radial in one ray; whether this is the right posterior ray cannot be ascertained, as the infrabasals are concealed by the top columnal; but it will be seen from the figure that the radial in that ray is not in any way dwarfed or different in shape from the others, as in *Ichthyocrinus*. I therefore consider the extra plate in this ray as a mere case of sport, having no relation to a radianal. I have two other good specimens with arms complete, neither of which show any additional plate. The number of secundibrachs is constant at 4 except in one ramus of one ray in each specimen. Besides these I have two other specimens from the same locality showing the base and parts of the ray; all five specimens have the same broad base, with basals wholly included in the column facet.

The question of the horizon of this species has been discussed under the genus.

*Type.* In the United States National Museum, Troost collection. The other specimens figured are in the author's collection.

*Horizon and locality.* Lower Carboniferous, New Providence shales (Knobstone); White's Creek Springs, Tennessee.

## **WACHSMUTHICRINUS** Springer

*Plates XLIII, XLIV*

*Wachsmuthicrinus* Springer, Amer. Geologist, XXX, 1902, p. 95; Jour. Geology, XIV, 1906, p. 510.—Zittel-Eastman, Textbook Palaeontology, 1913, p. 205.

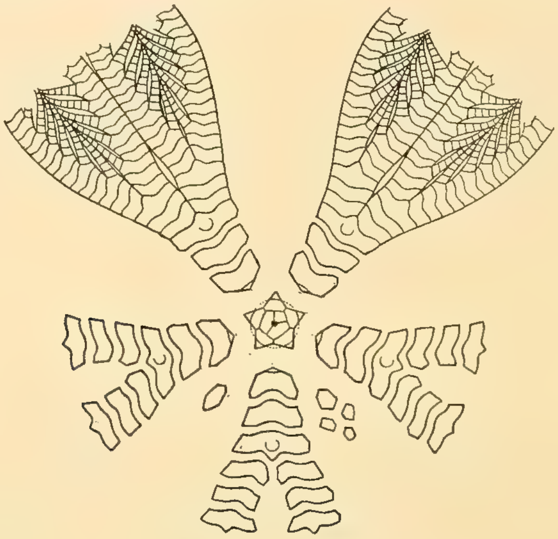

Fig. 43. *Wachsmuthicrinus*

Ichthyocrinidae with rays above radials separated in lower part by solid plates, or in contact all around. Crown elongate, expanding from radials up. Infrabasals entirely within ring of basals. Posterior basal not differentiated. No radianal, or anal. Interbrachials present or absent; when present few and variable, and the rays meeting above them. Primibrachs two. Arms heterotomous; rays in twenty main divisions, with simple ramules inside dichotom; outside margins may interlock. Column large, expanding proximally.

*Genotype. Forbesiocrinus thiemei* Hall.

*Distribution.* Lower part of Lower Carboniferous; United States and (?)Mountain limestone, England.

This genus was proposed by me in 1902 for a type represented by several species which differed from all other genera of the Flexibilia then known, with two exceptions, in the pentamerous symmetry due to the complete absence of either anal or radianal plates. Those exceptions are *Metichthyocrinus* and *Nipterocrinus,* which are so different in other respects that their generic distinctness is apparent at a glance. *Wachsmuthicrinus* may be called a heterotomous *Ichthyocrinus* without a radianal, or, more exactly, a heterotomous *Metichthyocrinus*. Superficially it bears a close resemblance to the Devonian *Synaptocrinus nuntius.* The pentamerism is very marked and constant; in a considerable number of good specimens only a slight deviation from it has been observed in a few cases where the posterior basal is a shade larger than the others, and in an abnormal specimen in which two basals (which ones cannot be ascertained) touch the first interradials (Pl. XLIII, fig. 3).

This complete elimination of disturbing elements, combined with the distinct heterotomy of the arms, forms a high degree of specialization, under which there is some variation in characters elsewhere of generic importance. One of these is the presence or absence of interbrachials. Ordinarily the function of interbrachials is to fill spaces in the expanding calyx of the growing crinoid; therefore they increase in number with the maturity of the individuals, and may be expected to be fewest or entirely absent in the smaller specimens. But that rule does not hold good in *Wachsmuthicrinus.* The Knobstone species, although attaining a large size, are uniformly without any trace of interbrachials; the Lower Burlington species, as a rule, have them;—not only the large *W. bernhardinae* and *W. spinifer,* but also the smallest specimens of what have always been considered *W. thiemei* (Pl. XLIII, figs. 6, 7, and about 15 others not figured). But the type and another one very similar to it (figs. 1, 2), two of the largest specimens of that species ever found, are without any definite interbrachials, and some of the rays interlock perfectly for a considerable distance. These specimens are all from the same locality, and have such an entirely similar facies in other respects that they cannot be separated specifically on the difference of interbrachials.

It is evidently here not a question of individual growth so much as of sporadic variation, so that a character ordinarily of generic value is subordinated to specialization in another line, and is worthless. The variations in *W. thiemei* have been the subject of frequent comment in the various discussions of the genus *Taxocrinus,* and were also the cause of the reference of some of the species to different genera. *W. spinosulus* was described by Miller and Gurley as an *Ichthyocrinus* solely on account of its having no interbrachial plates. There is also within the genus, as in *Dactylocrinus,* a tendency to modification of the arm branching in the direction of dichotomy, by an increase in the relative size of the ramules, and of the intervals between them as in the Knobstone species (fig. 15). Another illustration of the tendency to variation in this genus is found in the growth of nodes and spines on the axillaries, especially the axillary primibrachs where they sometimes become of enormous size. This also is not a matter of individual growth, but it is either a specific character or a purely sporadic variation, as some of the smaller specimens have ample spines, and some of the largest only very small nodes, or none at all.

The basal structure brings the genus clearly within the family Ichthyocrinidae. The infrabasals lie within the basal ring, completely under the column (Pl. XLIII, figs. 3, 5, 7). They become in some species relatively somewhat larger than in any other genus of the family, and occasionally tend to develop a slight flange-like extension over a small part of the basals, but none extending to the limits of the column facet.

*Wachsmuthicrinus* is restricted to the earliest formations of the Lower Carboniferous, occurring first in the Knobstone of Indiana, Kentucky and Missouri, and ranging throughout the two beds of the Burlington limestone. *W. thiemei,* of the Lower Burlington, is well represented in the collections made at Burlington, though never abundant, and it has been identified from New Mexico; all the others are extremely rare. The genus probably occurs in the British Lower Carboniferous, from which I have figured a defective specimen. The tendency to variation already mentioned makes the differentiation of species rather unsatisfactory; either several new ones must be recognized among specimens from the same locality and horizon, or a wide latitude must be admitted for what seems to be the leading species in each formation. The latter course seems preferable. This leaves one species from the Knobstone, four from the Burlington, and one, not very characteristic, from Scotland; these are arranged as follows:

### The Species of Wachsmuthicrinus

I. Ramules small.
BB very small, entirely covered by column.
No iBr.
Surface finely pustulose.....................................*W. spinosulus.*
BB extending beyond column.
iBr present or absent.
Surface smooth.
Rays longitudinally angular.
Small nodes on RR and axillaries; iBr one or two.
Ramules at intervals of 5 to 3............................*W. thiemei.*
Large spines, chiefly on axillary IBr.
iBr 1 to 4 or more.
Ramules at intervals of 3 to 2........................*W. spinifer.*
Rays rounded. Specimens very large.
Very small nodes on axillaries.
iBr and iIIBr numerous.
Ramules at intervals of 2 to 1...................*W. bernhardinae.*
Rays widely divergent.
iBr numerous, first very large.
Ramules at intervals of 3 to 2........................*W. iowensis.*
II. Ramules very large.
iBr well-developed.
Rays abutting above them...............................*W. ponderosus.*

### **Wachsmuthicrinus spinosulus** (Miller and Gurley)

*Plate XLIII, figs. 11-16*

*Ichthyocrinus spinosulus* Miller and Gurley, Bull. 5, Illinois St. Mus., 1894, p. 44, pl. 5, fig. 4.

Attaining a large size. Crown elongate, in mature specimens spreading upward almost to the level of infolding, where height to width is about 1.25 to 1; spread of calyx from column to IAx, 1 to 2. Base concave, with radials projecting downward from the rim, often in strong nodes. Cross-section quinquelobate, side outline nearly straight. Rays rounded or slightly angular, in some specimens marked by prominent nodes and strong transverse ridges on lower brachials and axillaries, in others nearly smooth and simply convex; rami heavy, equal. Crown of mature specimen, 50 mm. high by 40 mm. wide; base at outside of concavity, 15 mm.; column, 12 mm.

IBB and BB completely covered by column, the former apparently resorbed in one imperfect specimen. R and IBr widening regularly upward, IIBr 3. Rays interlocking in typical specimens as high as the last IIBr; in some diverging immediately above IBr$_1$ or IIBr$_1$. No regular interbrachials in the spaces thus formed, and no room for any touching radials. Ramules small, commencing on third to fifth IIIBr, and continuing usually on every third brachial to the number of 8 to 10 before infolding; exceptionally at intervals of 6 or 7 brachials. Column large, expanding next to calyx.

Like *W. thiemei,* this species includes two or three forms which might be separated, but the specimens occur in a limited horizon, and the range of variation is about the same as in that species. Superficially the specimen represented on Plate XLIII, figure 14, looks very different from the type, but the surface characters of the former have been removed by erosion; the two are much more alike in essential features than they are like figure 15, which I should not hesitate to separate on account of its diverging arms and very long intervals between ramules, if we did not have the same variations in *W. thiemei.*

None of the Knobstone specimens show any interbrachial plates; the spaces in figure 15 were probably not so occupied, as the margins of the brachials are rounded, and show no sign of sutural faces. The young specimen, figure 13*a, b,* is interesting as showing the completely different proportions of the plates from those of mature forms. Although the basal plates are usually prominent in young individuals, they are in this one completely hidden by the column, thus confirming the great reduction of these plates which is characteristic of the species.

As all the specimens are flattened I have given an outline restoration of the type, accurately drawn to scale.

*Types.* The original of figure 11, is in the University of Chicago; the others in the author's collection.

*Horizon and locality.* Base of the Lower Carboniferous, Knobstone Group (New Providence shales); Clark County, Indiana; Bullitt and Lincoln counties, Kentucky.

## **Wachsmuthicrinus thiemei** (Hall)

*Plate XLIII, figs. 1-10*

*Forbesiocrinus thiemei* Hall, Jour. Boston Soc. Nat. Hist., VII, 1861, p. 317; Descr. New Species Crin., p. 8; Bull. I, New York St. Mus. Nat. Hist., Photographic Plates, 1872, pl. 7, fig. 4.

*Taxocrinus thiemei,* Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, (2) IX, 1865, p. 139.—Meek, Amer. Jour. Sci., (3) VII, 1874, p. 191.—Wachsmuth and Springer, Revision Palaeocrinoidea, I, 1879, p. 49; N. A. Crinoidea Camerata, 1897, p. 139.—Whiteaves, Contrib. Canadian Palaeontology, I, pt. 2, 1889, p. 94.—Keyes, Geol. Surv. Missouri, IV, 1894, p. 223, pl. 30, fig. 5.

*Rhodocrinus (Taxocrinus) thiemei,* Shumard, Trans. Acad. Sci. St. Louis, II, 1866, p. 398.

*Wachsmuthicrinus thiemei,* Springer, Amer. Geologist, XXX, 1902, p. 96; Jour. Geology, XIV, 1906, pl. 6, fig. 19.

Not *Taxocrinus thiemei,* Meek and Worthen, Geol. Surv. Illinois, V, 1873, p. 399, pl. 4, fig. 1.

Type of the genus.

A medium-sized species. Crown elongate, spreading upward; widest about first ramule, where height to width is 1 to 1.5; spread of calyx to that level from outside of truncate base, 1 to 3. Cross-section at IAx sharply pentagonal, side outline to that level a notched line with little curvature. Base excavate, with RR projecting slightly downward from the margin. Sutures sinuous. Surface smooth or finely granular. Mature crown, 33 mm. high by 24 mm. wide; base, 8 mm.; column at base, 5 mm.

IBB small, within ring of BB, sometimes with a slight flange projecting under BB. BB projecting in triangular points beyond the column. iBr 1 or 2 small plates, or absent. RR and IBr sloping to a sharp, angular longitudinal median ridge, with more or less prominent angular nodes; they increase regularly in width upward except when an interbrachial is present, when the first primibrach is the shortest of the three plates. IIBr 3. Rays and their divisions more or less angular, interlocking or closely abutting on the outer sides, and meeting above iBr, when present; axillary plates frequently marked by small nodes; rami equal, tapering very gradually; ramules small, 9 or 10 in mature specimen before infolding; first and second ramules usually on fourth and fifth IIIBr, and above that on every third, or in the distal parts every second, brachial. Column large, expanding next to calyx for about 25 uniformly thin ossicles, beyond which longer rounded columnals begin to alternate with them, these in turn doubling their length with increasing intervals between them.

This species, rare except at one place, has always attracted much attention from the Burlington collectors, who were careful to save every fragment found. Nearly all of these, amounting to about 25 specimens from the principal collections made during fifty years, are in the Museum of Comparative Zoology and in my own collection. All are derived from the same horizon within a very limited area, and they have a common facies which seems to mark them as one species. This includes specimens with rays and arms interlocking to various heights, some with arms diverging above the axillary leaving a vacant space, and others with one or two, rarely three, interbrachials; some of the smallest specimens have interbrachials, and the largest none; and there are all kinds of intermediate stages. Also while the ramules above the first two usually occur on every third brachial, an occasional specimen (like Pl. XLIII, fig. 9) has ramules relatively so large and far apart as to approach dichotomy. But the general type is definite and easily recognizable; all have the sharply pentagonal calyx, angular rays, and basals visible outside the column. The tendency to develop nodes on the axillaries and lower brachials is quite constant in many specimens, but it cannot be said that there is such a gradation from these to the immense spines of *W. spinifer* as to require their consolidation into one species.

The species was named in honor of Dr. Otto Thieme, of Burlington, Iowa, by whom the type specimen was found. A physician by profession, he was a man of versatile talents, of scientific habits, and an ardent lover of nature. His attention was attracted in the later fifties to the extraordinary richness of the Burlington limestones in crinoidal remains, and he was the first who began their systematic collection after the few obtained by Owen's expedition in 1848-49. It was through his influence that Wachsmuth became interested in the subject, and began in the field the studies which led to the numerous publications on the crinoids with which his name was afterwards connected.

*Types.* The original used in Hall's description is in the Museum of Comparative Zoology, Harvard College. The other specimens figured are in the author's collection.

*Horizon and locality.* Lower Carboniferous, Lower Burlington limestone; Burlington, Iowa—also reported by Keyes from Hannibal, Missouri.

### **Wachsmuthicrinus spinifer** (Hall)

*Plate XLIV, figs. 1-5*

*Forbesiocrinus spinifer* Hall, Jour. Boston Soc. Nat. Hist., VII, 1861, p. 318; Descr. New Species Crin., p. 9 (*spiniger*).
*Taxocrinus spinifer,* Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, IX, 1865, p. 140.
*Taxocrinus thiemei,* Meek and Worthen (not Hall), Geol. Surv. Illinois, V, 1873, p. 399, pl. 4, fig. 1.

Generally similar to *W. thiemei,* except in the extremely prominent spines, and in having the ramules at shorter intervals. The spines, which give to the species a very unusual appearance for this group, are almost wholly confined to the axillary primibrach, which is produced to such an extent as to resemble the spines on the radial dome-plates in the Camerate genus *Dorycrinus.* In *W. thiemei* the nodes sometimes become sharp, like spines, but they are small, short, and distributed throughout the ray; whereas here the spiniferous tendency is concentrated on one plate, the other axillaries showing it but rarely. The ramules, as shown by four specimens, seem to be constantly rather closer together, being on every second brachial in the upper half of the rays, and the intervening brachials becoming short and pointed. There is also greater development of interbrachials in this species than in the last, these plates occurring alike in large and small specimens.

The species has been found in the equivalent of the Lower Burlington strata at Lake Valley, New Mexico. I have also figured some isolated spinous axillary plates from the Kinderhook beds at Fern Glen, Missouri, indicating that this or a similar species existed at that horizon, slightly below the beds at Burlington.

Meek and Worthen considered the species synonymous with *W. thiemei,* and so figured the fine specimen here shown by Plate XLIV, figure 1*a*.

There has been some confusion as to the name, whether it should be written *spinifer* or *spiniger,* having been used by Hall in the latter form in his preliminary description. But this pamphlet, so far as can be ascertained from the dates borne by the publications themselves, did not appear until after the full description in the Journal of the Boston Society of Natural History, January, 1861, in which the name is printed "*spinifer.*"

*Type.* The type of Hall's description, formerly in the collection of Dr. Charles A. White, is a very imperfect specimen, and was not accessible when the drawings for this work were prepared. It is now in the author's collection, as are the other specimens here figured, except that of figure 1*a,* which is in the Museum of Comparative Zoology, Harvard.

*Horizon and locality.* Lower Carboniferous, Lower Burlington limestone; Burlington, Iowa, and Lake Valley, New Mexico; and also Kinderhook, Fern Glen, Missouri.

### **Wachsmuthicrinus bernhardinae** n. sp.

*Plate XLIV, figs. 6-7*

The largest species of the genus. Crown elongate, spreading rapidly to level of first ramule, where height to width is 1 to 1.1, and spread of calyx, 1 to 3.5. Rays rounded, interbrachial areas deeply depressed. Cross-section quinquelobate; side outline curved. Sutures strongly sinuous. Surface smooth, with very small nodes on lower and many of the upper axillaries. Interbrachial system strongly developed, there being 8 or 10 good-sized plates in the primary axil, and nearly as many smaller ones in the second, and some even in the third. Rami equal, and deeply rounded. After the first two or three, which have intervals of 4 and 3 brachials, the ramules occur on every second plate throughout the rays, to the number of over sixteen before disappearing. Otherwise as in *W. thiemei*. Height of crown (allowing for foreshortening by pressure), 85 mm.; width, 46 mm.; diameter of base, 13 mm.; of column, 11 mm.

The detached base shown by Plate XLIV, figures *7a-c*, has been in my collection for about forty years along with numerous specimens of *W. thiemei*, but labelled as a probable new species on account of its size so entirely out of proportion to that of other known specimens. Finally however, this was confirmed by the discovery of the remarkably perfect specimen which furnishes all the other characters. It is somewhat crushed at the base, otherwise the crown would appear longer. In its rounded rays and almost complete obliteration of nodes and angularities it differs markedly from all specimens of *W. thiemei*, as it does also in the profuse development of interbrachials, which produces a separation of the rays and their divisions different from that seen even in the specimens of that species having interbrachials. No other specimens have been found.

The magnificent specimen illustrated by figure 6 on Plate XLIV was found by Mrs. Bernhardina Wachsmuth, widow of my early associate for whom the genus is named; a noble woman, to whose memory I esteem it a privilege to dedicate this fine species.

*Type.* Author's collection.

*Horizon and locality.* Lower Carboniferous, Lower Burlington limestone; Burlington, Iowa.

### **Wachsmuthicrinus iowensis** n. sp.

*Plate XLIV, fig. 8*

Similar to *W. thiemei,* but with rays and their divisions strongly divergent, and numerous interbrachials, beginning with a very large one resting on the shoulders of the radials. The rays are angular below, with small nodes on the lower brachials, and rounded without nodes above. Ramules about every third brachial. There is but a single specimen, considerably flattened in a vertical direction by pressure, which may increase the apparent divergence of the rays.

I have hesitated to propose a new species upon this single and somewhat unsatisfactory specimen, and if it belonged to the same horizon as those of *W. theimei* I should regard it as merely a further extension of the variations of that species. But it occurs in the Upper Burlington beds, associated with *Dorycrinus missouriensis* and other characteristic fossils; and very few species are known to pass unchanged from the Lower beds to this horizon. This fact would indicate that the increase in size and number of interbrachial plates, and consequent greater spreading of the crown, had probably become a fixed character. I should expect that other specimens, if ever found, would confirm the separation. This is the latest occurrence of the genus, and it must have been almost extinct, as no other specimen has ever been found from the Upper beds in all the collections made at Burlington during half a century.

*Type.* Author's collection.

*Horizon and locality.* Lower Carboniferous, Upper Burlington limestone; Burlington, Iowa.

### **Wachsmuthicrinus ponderosus** n. sp.

*Plate XLIV, figs. 9a-c*

A large species. Crown elongate, with rays in close contact above iBr. Interbrachials well developed as high as the third axil. Rays and their divisions rounded; the outer one largest. Ramules very large, branching again, approaching the main ramus in size at about the third bifurcation, and probably extending to its full length. Sutures sinuous, surface of rays finely pustulose. Crown, 45 mm. high, and about 38 mm. wide at the second bifurcation.

The imperfect condition of the specimen precludes a more detailed description. The entire calyx is exfoliated below the IIBr, and the suture lines are traced with some difficulty on the surface of the internal cast. So far as can be ascertained the crown is perfectly symmetrical, with a series of three or four interbrachial plates in the primary axil, and others in the second and third, and without any differentiation of the anal side. The base cannot be made out. If this interpretation is correct the form must fall within this genus as a variant in the matter of large ramules, somewhat like *D. tardus* in *Dactylocrinus;* it is of special interest as the first indication of the genus outside of America.

*Type.* British Museum, No. 75696.

*Horizon and locality.* Lower Carboniferous; Jedburgh, Scotland.

## **SYNEROCRINUS** Jaekel

*Plates XLII; LXXV, figs. 12, 13*

*Synerocrinus* Jaekel, Zeitschr. d. deutsch. geol. Gesell., XLIX, for 1897 [1898], p. 47.—Bather, Rep. British Assoc. for 1898 [1899], p. 923; Treatise on Zoology (Lankester), pt. 3, 1900, p. 190.—Springer, Amer. Geologist, XXX, 1902, p. 95; Jour. Geology, XIV, 1906, p. 519.—Von Zittel, Grundzüge Palaeontologie, 1910, p. 166.—Zittel-Eastman, Textbook Paleontology, 1913, p. 205.

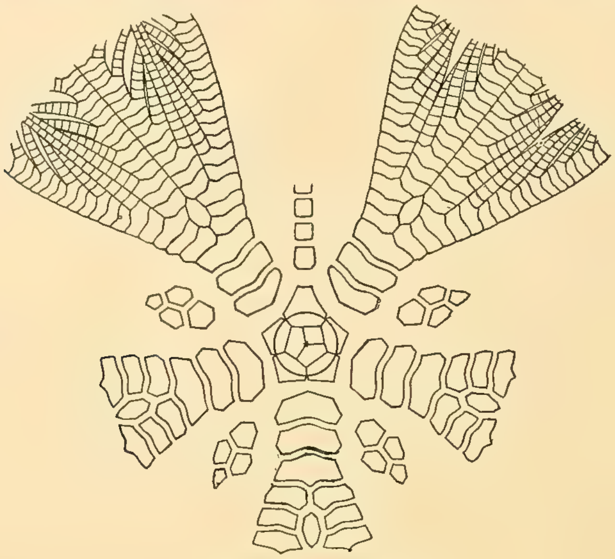

FIG. 44. *Synerocrinus*

Ichthyocrinidae with rays above radials separated in lower part by solid plates. Crown elongate to rotund, expanding from radials up. Infrabasals entirely within the ring of basals. No radianal. Anal *x* united by suture to posterior basal, and more or less to adjacent brachials, followed by a tube. Interbrachials few; rays usually meeting above them, but not interlocking. Primibrachs two. Arms heterotomous; rays in twenty main divisions with simple ramules inside of dichotom. Column large, enlarging proximally.

*Genotype. Forbesiocrinus incurvus* Trautschold.

*Distribution.* Upper part of Lower Carboniferous; Russia and Scotland.

Considered with regard to the characters on which family distinction is based, *Synerocrinus* stands on the border line between the Taxocrinidae and the *Ichthyocrinidae.* The anal structure is essentially that of a tube bordered by perisome, but this tube does not exactly originate on the posterior basal; and therefore the genus may be held within its family without stretching the definition to the breaking point. Superficially the anal side of the specimen looks like that of a Taxocrinoid (Pl. XLII, fig. 6*a*), but the instructive dissection in figure 8*a* shows that the actual structure is essentially different. The posterior basal does not directly support the tube, but is suturally united to another plate which does; and this plate is also suturally united for part of its height to plates of the adjacent rays at both sides. The fossae on the distal face of the posterior basal and the side of the left radial are clearly shown in figure 8*a*, and the exact relation of the first anal plate to the others may be seen in the sketch of these parts, figure 7, where the tube is drawn without the perisome, which would doubtless appear in perfect specimens. The inner margins of the rays above the sutures connecting them with the first anal plate are rounded just as in the Taxocrinoids, but the posterior basal and a part of the adjoining plates are not. Thus the genus will fall beyond the limits of the Taxocrinidae, but by a very small margin. Upon other grounds its affinities with the Ichthyocrinidae are so evident as to require little discussion. A glance at figure 4*b* shows that the base is fundamentally that of the family, and the arm structure is that of the heterotomous section of it. But for the modification of the anal series to a tube instead of suturally attached plates, there would be nothing to distinguish this genus from *Dactylocrinus,* of which it may be regarded as a successor. Its geological position is in the upper part of the Lower Carboniferous; the Moscow limestone and the Hurlet bed of Scotland, which furnish its only species, may be correlated with the latest division of the American Lower Carboniferous, the crinoidal fauna being nearer to that of our Kaskaskia than to any other.

Being thus one of the last survivors of the Sagenocrinidae, the strongly Taxocrinoid character of its anal structure may be interpreted as a degenerative feature, with a tendency to return to the primitive weak anal side. An analogous tendency to weakening of the anal side may be seen in *Amphicrinus.*

The fortunate acquisition of a partially disintegrated specimen enables me to throw new light upon the more detailed structures of this form, especially of the tegmen, which is preserved in a somewhat disturbed condition (Pl. XLII, figs. 8*a*-*c*). The most striking feature is the beautiful preservation of the posterior oral, the madreporic nature of which appears in the principal figure 8*n,* but in greater detail in figure 8*o,* which is a direct photographic enlargement, accurate to the smallest pore. The calcareous substance of these plates is as perfect as when deposited, white in color, and unchanged by chemical action or contact with the matrix. This posterior oral is very much larger than the others, two of which are preserved; they were evidently substantially similar to the orals of *Taxocrinus intermedius.*

It is rather remarkable that while the perisome is perfectly preserved, although considerably displaced, I have been unable positively to identify any ambulacra; in one or two places there is a semblance of alternate arrangement of plates, but nothing so well defined as those found in *Taxocrinus* and *Onychocrinus.* Even in the arms where the perisome is intact there are no covering plates, but it seems to form a roof for some small longitudinal grooves (fig. 5*b*). Some interesting details of articulation and sutural union are shown among the figures. The fossae in general are of the interrupted character found in *Forbesiocrinus agassizi;* but there was room for large masses of ligaments.

The genus *Synerocrinus* was proposed by Jaekel solely on the basis of its heterotomous arm structure, with *Forbesiocrinus incurvus* as the type and only species.

### **Synerocrinus incurvus** (Trautschold)

*Plates XLII, figs. 1-9; LXXV, figs. 12, 13*

*Forbesiocrinus incurvus* Trautschold, Bull. Soc. Imp. Moscow, XL (No. 3), 1867, p. 31, pl. 4, figs. 4, 5*a*-*b,* and text diag.; Kalkbr. von Mjatschkowa, 1879, p. 126, pl. 14, fig. 11, pl. 15, fig. 3.

*Taxocrinus incurvus,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 48.

*Synerocrinus incurvus,* Jaekel, Zeitschr. d. deutsch. geol. Gesell. xlix, for 1897 [1898], p. 47.—Bather, Treatise on Zoology (Lankester), pt. 3, 1900, p. 190, fig. 111.

*Encrinites stoloniferus,* Fischer de Waldheim, Oryctogr. Gouv. Moscou, 1st Ed., 1830, pl. 41, figs. 1, 2.

*Encrinites moniliformis,* Fischer de Waldheim (in part), Oryctogr. Gouv. Moscou, 2d Ed., 1837, p. 151, pl. 41, figs. 1, 2 (*stoloniferus* on plate).

Type of the genus.

A large species. Crown elongate, rounded below from column facet, expanding upward; widest about $IIBr_3$, where average height to width is 1 to 1.4; spread of calyx from base, 1 to 2.6. Cross-section obtusely quinquelobate; side outline strongly curved. Base indented, with a very shallow depression entirely filled by the upper columnal. Surface smooth. Medium-sized crown 42 mm.

high by 36 mm. wide; diameter of base at perimeter of column 10 mm.; of column at a distance of 11 mm., below 6 mm. Maximum specimen: crown, 70 mm. high, 43 mm. wide; base, 17 mm.

IBB small, less than half the diameter of column facet, entirely within ring of BB. BB extending as pentagons beyond the column; post. B rising nearly to height of radials, truncate, followed by one anal plate suturally joined to it, and to a greater or less extent to RR and $IBr_1$; this is followed by a vertical series forming the back of a tube. iBr 3 to 5 or 6 of about equal size, narrowing to an apex, with rays meeting above; iIIBr 1 to 3, with inner branches of rays meeting above them. RR and IBr of about equal size; IIBr usually 3, increasing in width upward. Rays and their divisions rounded; rami about equal. Ramules large, usually on every third brachial, sometimes second or fourth; the first ramule considerably the largest. Column large, expanding near the calyx, covering the inner half of the basals, and extending the full width of the base; upper columnals thin, there being 25 of them in a length of 10 mm., within which distance they diminish nearly one-half in diameter; beyond this the column is cylindrical.

This fine species was described by Trautschold in 1867 under the name *Forbesiocrinus incurvus*, with good figures of characteristic specimens, and a text diagram; and in 1879 he gave a new description and a new photographic figure of one of his types, together with figures of another much larger specimen. A specimen apparently of the same species was figured by Fischer de Waldheim in the second edition of his Oryctographia, 1837, under the name *Encrinites moniliformis*. In the first edition, 1830, the same figures were listed as *Encrinites stoloniferus*. As there was no pretense of describing a new species, and the figures did not bring out intelligibly the essential characters of the form, I see no reason for withholding from Trautschold his well-earned priority.

The present description and discussion of the genus are based upon a series of six good specimens in my own collection, and a set of excellent casts of the specimens in the University of Moscow most obligingly prepared for me by Professor A. P. Pavlow, Director of the Geological and Paleontological Museum. Among all these, and some that I have seen elsewhere, only one shows the exact character of the base (Pl. XLII, fig. 4*b*), although having once understood it I can recognize the same structure in Fischer de Waldheim's figure 2. On account of the great width and thinness of the upper columnals they did not readily separate from the base, which in broken specimens tended to pull off with them.

Among the crinoids found by Mr. James Wright, Jr., in the Hurlet limestone of central Scotland, further mentioned under *Amphicrinus*, are four specimens of *Synerocrinus;* one is of large size, similar to those of figures 4 and 5*a*, and another, from a somewhat lower bed, smaller like 6*a*. I have figured these two on Plate LXXV, figures 12, 13, from which it can be seen that they are unmistakably of this genus; and in the form and proportions of the crown and the characters of the strong heterotomous rays I can find nothing to distinguish them from the Russian species.

*Types.* Trautschold's originals are in the Mineralogical Museum of Breslau, Germany. The other Russian specimens figured are in the author's collection, and those from Scotland are in the collection of James Wright, Jr., Kirkcaldy, Scotland.

*Horizon and locality.* Upper part of Lower Carboniferous, associated with *Eupachycrinus, Cromyocrinus, Stemmatocrinus, Phialocrinus*, etc., comparable to the Kaskaskia of America. Near Moscow, Russia; Roscobie and Ardross, Scotland.

## **AMPHICRINUS** Springer

*Plates XL, figs. 9-11; LX, figs. 12a, b*

*Amphicrinus* Springer, Jour. Geology, XIV, 1906, p. 518; (Springer MS.), Wright, Trans. Edinburgh Geol. Soc., X, pt. 2, 1914, p. 161.—Zittel-Eastman, Textbook Paleontology, 1913, p. 205.

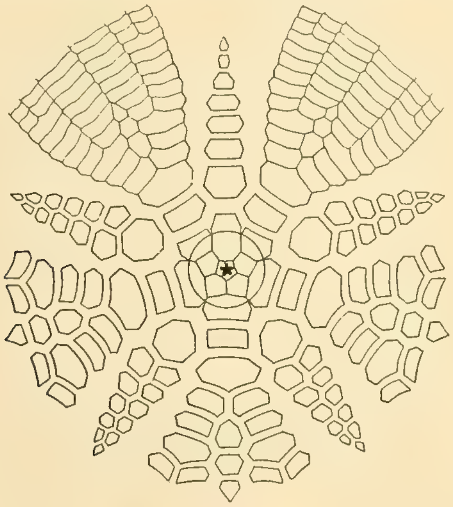

FIG. 45. *Amphicrinus*

Ichthyocrinidae with rays above radials partly separated by solid plates, arched over by brachials. Crown ovoid to subglobose, expanding from radials up. Infrabasals entirely within the ring of basals, sometimes resorbed. No radianal. Anal *x* followed by others in a single row. Interbrachials numerous, in more than one row. Primibrachs two. Arms isotomous, interlocking. Column large, covering infrabasals and part or all of basals.

*Genotype. Amphicrinus scoticus* Springer.

*Distribution.* Upper part of Lower Carboniferous to Lower Coal Measures; Scotland and the United States. The latest known genus.

This genus was proposed by me to receive certain specimens from the British Carboniferous which could not be placed under any other genus previously described. It bears a general resemblance to the *Forbesiocrinus* type, having the anal and interbrachial areas filled with solid plates, although differing in the complete arching over of these plates by the abutting rays and their lower divisions; but it is remarkable for having, contrary to the rule in the crinoids generally, the anal interradius smaller than those of the regular areas—a character which distinguishes it readily from all other of this family. In the type and only well-known species each regular interradius has two vertical columns of large plates resting upon the first interbrachial, and extending for five or six ranges; while the anal interradius has but a single series of such plates. Its family position is determined by the remarkably small size of the basal circlet, which is usually much less than that of the column facet, and by the tendency to resorption and sometimes to complete disappearance of the infrabasals.

In the latter respect it exhibits the tendency of the family to the fullest extreme. Figure 10 of Plate XL shows the infrabasals partially resorbed, fitting accurately within the ring of basals and meeting them by their inner edges; while in figure 9 they have completely disappeared, not by being pulled off with the stem as in *Forbesiocrinus,* but by atrophy as a morphological feature in that specimen—just as they do in the Recent species *Endoxocrinus parrae*—and the space they should have occupied is partly represented by the large lumen of the axial canal.

A curious degenerate tendency appears in the anal interradius, where the lower plate is wanting in most of the specimens.

In the basal structures and general habitus the genus is similar to *Euryocrinus,* but differs from it in the relative development of the anal side, and in having only two primibrachs instead of three. On the latter character alone it might be held to be a variant, as in the case of *Forbesiocrinus agassizi;* but the interbrachial structure strongly differentiates it, and this correlation of characters is the fundamental ground for the generic separation which I made.

The type species is from the Hurlet limestone of the Lower Carboniferous of Scotland, a different and much later horizon than that of *Euryocrinus concavus* and *E. rofei,* and substantially equivalent to the American Kaskaskia. Until recently but few specimens have been found, and it is rather curious that this hitherto unnoticed fossil should be one of those most prominently figured by David Ure in 1793. A second species has been discovered in the Lower Coal Measures (Pennsylvanian) of America, which makes this genus the latest known survivor of the Flexibilia.

## **Amphicrinus scoticus** n. sp.

*Plate XL, figs. 9-11*

*Amphicrinus scoticus* Springer MS., Wright, Trans. Edinburgh Geol. Soc., X, pt. 2, 1914, p. 161, pl. 19, figs. 3, 4.

*Encrinus,* Ure, History of Rutherglen, 1793, p. 325, pl. 18, figs. 13, 16.

*Forbesiocrinus* spp. Wright, Trans. Edinburgh Geol. Soc., X, pt. 1, 1912, pp. 49-60, pl. 5, fig. 8, pl. 6, figs. 1, 2, pl. 7, fig. 1.

? *Euryocrinus* sp. Wright, Trans. Edinburgh Geol. Soc., X, pt. 1, 1912, pl. 7, fig. 3.

Type of the genus.

Specimens above medium size. Crown rotund, higher than wide; with small base, and closely abutting, infolding rays. Surface smooth. Greatest width of average specimen at IIIBr$_3$, about 35 mm.; height 40 mm.; spread of calyx from base to top of iBr, about 1 to 3.5.

Base very shallow, and broadly expanding to above the second ray division. IBB very small, lying entirely within BB, sometimes partly or wholly resorbed. Post. B more than twice as large as the others, and rising far above their level; the other four small, usually covered by the column, exceptionally visible as small triangles outside the column facet. RR small, only partly visible beyond the column, the two posterior ones smaller than the others. IBr 2, larger than RR, somewhat widening upward; the next two orders of brachials fully as large. IIBr 3, increasing in width upwards; IIIBr 5 or 6. Arms flat, and following the general curvature; interlocking closely above iBr and iIIBr by zig-zag lines, and infolding at about the fifth order of brachials. Sutures arcuate, more strongly marked in distal parts of rays. Post. B truncate, followed by a single diminishing series of plates smaller than one of the two columns of interbrachials; anal *x* often defective or wanting. First iBr larger than the anal, angular above, supporting two rows of large plates in 5 or 6 ranges; iIIBr present, and in mature specimens they occur in similar double rows. Column facet very large, sharply and deeply indented, double the usual diameter of the basal circlet excepting the posterior basal, and involving about half the radials; column composed near the calyx of thin ossicles, diminishing in diameter downward.

This species is founded upon two specimens in the British Museum, Nos. E7422 and E640, from the Lower Carboniferous at Roscobie, Fifeshire, Scotland, which I have been permitted by the authorities of that Institution to figure and describe. Both are vertically compressed, so that the shallowness of the base is exaggerated. In the principal specimen (Pl. XL, figs. 9*a, b, c*) enough of the infolded arms is preserved lying over the top to give a definite impression of their character. The other one (fig. 10) is evidently a mature individual in which the intersecundibrachs are developed into a double series proportionally as large as the interbrachials. A noteworthy feature of the species is the unequal size of the radials, the two posterior ones being much reduced by encroachment of the very large posterior basal, somewhat as in *Parichthyocrinus;* the relatively enormous size of this plate is quite remarkable, when we consider the disproportionate smallness of the posterior area as a whole.

These two specimens are of somewhat peculiar interest, bearing upon the relation between the presence or absence of infrabasals and the orientation of the axial canal. In figure 10 the infrabasals are small but distinct, and are considerably encroached upon by the axial canal, which is stellate, and its angles are directed interradially; the same condition exists in another specimen in the British Museum, not figured, having only base and radials preserved. In figure 9*b,* however, and two other specimens since discovered, infrabasals have been entirely resorbed, and the axial canal cutting the edge of the basals is almost radial in position, following partly the interbasal sutures, and partly the edges of the plates. This is the nearest approach that I know of to a change from a dicyclic to a monocyclic base, accompanied by a corresponding change in orientation of the axial canal.

I have figured another specimen from Lesmahagow, Scotland, belonging to Mr. R. Dunlap, in the hands of Dr. Bather to whose courtesy I am indebted for the opportunity to examine it; this gives a better idea of the general appearance of this form than the others (Pl. XL, figs. 11*a, b*). One side of the crown is well preserved as far as the infolding of the arms, but unfortunately the anal interradius above the basal is not visible. The flat surface, and the close interlocking of the rays and their divisions above the interbrachial spaces, are well shown in this specimen.

Attention must be called to some interesting specimens clearly belonging to this species figured by Ure in his History of Rutherglen, 1793, plate 18, figures 13, 16;—one showing the arms complete from the secundibrachs up, and another a detached base. The figure of the latter does not indicate the posterior basal, but with the scant knowledge of these forms existing at that time it may easily have been ignored in the drawing. The large column overlapping the radials is entirely characteristic. Ure's account of the first specimen is as follows, page 325: "Figure 13, Plate XVIII, represents a fragment of *Encrinus,* the supposed head of the entrochi. The specimen from which it was taken was found, along with entrochi, shells, etc., in till incumbent on limestone at Hermayers, and it is the only one of the kind. The pieces of which it is composed are joined to one another by suture."

After the foregoing description was written Mr. James Wright, Jr., of Kirkcaldy, Scotland, published figures of several specimens of this form under the name *Forbesiocrinus,* without description or specific name. Later on he most courteously sent me for examination his entire collection of Flexibilia, found quite recently at Roscobie and Inverteil, Fifeshire, Scotland, which proved to be of the greatest interest. Among them are no less than twenty specimens of this species, and they confirm in a most satisfactory way the validity of the characters upon which the genus was founded. The doubling of the interbrachial series in the regular areas, contrasted with the single series in the anal area, is constant throughout except in a single interradius.

There is a peculiar tendency to infirmity at the anal side, where the anal *x* frequently appears sunken or as if gone altogether, but with the succeeding plates in the series perfectly solid and normal. This condition is seen in figures 9*a, b,* of Plate XL, and exists also in the original of figures 11*a, b;* 8 out of 12 of the new specimens preserving these parts show it in the same way, while four appear to have all plates of the anal series intact. Such a preponderance of specimens with the anal side so affected would seem to indicate a morphological change having some relation to the diminished size of that interradius characteristic of the genus.

This malformation of the anal area is not quite characteristically shown on Plate XL, figures 9*a, b,* where it appears as if the missing plates might have been accidentally broken out. In all the other specimens the margin of the sunken area is distinctly rounded, showing that for some unknown cause it had grown that way. Indeed it somewhat resembles the lower part of the posterior area in *Taxocrinus,* but there is no sign of any tube, and some plates firmly united to the rays at both sides are always found in the upper part. As this is the latest known genus of the suborder with the strong anal side, we may have here a case of degeneration tending toward a return to the primitive weak anal side, analogous to that of *Synerocrinus.*

It has been suggested that these depressions may be caused by parasitic shells, like those made by *Eulima* upon the calyx of *Ptilocrinus,* but they are scarcely regular enough in shape for that.

The tendency to resorption of the infrabasals is also remarkably shown by the new material—these plates being wholly resorbed in three specimens, partially so in nine; while in four others they remain intact. In each case where complete resorption has occurred, the axial canal is nearly or quite radial.

The above-mentioned fossils in Mr. Wright's collection are associated with a remarkable and hitherto undescribed crinoidal fauna, of which a very clear account, with photographic figures but without specific descriptions, is given in his papers (Trans. Edinburgh Geol. Soc., vol. 10, pt. 1, 1912; pt. 2, 1914). The fauna occurs in the Hurlet formation, a series of alternating sandstones, shales and limestones covering upward of one thousand square miles in Scotland; it represents the top of the British Lower Carboniferous limestone series passing gradually into Coal Measures. Among the other genera comprising this fauna are *Hydreionocrinus, Cromyocrinus, Zeacrinus* of the true *Z. wortheni* type, and *Synerocrinus.* This assemblage of crinoid forms at once suggests the equivalency of this horizon with that of the Russian Bergkalk near Moscow. It is also directly comparable with the Kaskaskia of the American Lower Carboniferous, with which its stratigraphic position preceding the Coal Measures precisely agrees.

*Types.* British Museum of Natural History, London, Nos. E7422, E640. The original of figures 11*a, b,* is in the collection of Mr. E. Dunlop, of Baillieston, Scotland, now in the Carnegie Trust Museum, Dunfermline.

*Horizon and locality.* Upper part of Lower Carboniferous, comparable to the Bergkalk formation near Moscow, Russia, and to the Kaskaskia of America. Invertiel, Roscobie, Lesmahagow, and Rutherglen, Scotland.

## **Amphicrinus carbonarius** n. sp.

*Plate LX, figs. 12a, b*

I have figured under this name an imperfect specimen, which is of special interest as being the latest known survivor of the Flexibilia as now limited by me to the Impinnata. It is derived from the Lower Coal Measures (Pennsylvanian) at Girard, Kansas, and has been lying in my collection for many years without a name, because the parts preserved are not sufficient to determine its generic characters. It is of an extremely flexible type, having broad and shallow ligament fossae somewhat like those of *Forbesiocrinus,* which it also resembles in the relative thinness of the lower plates. The only previously described genera approximating its geological position to which it might possibly belong are *Forbesiocrinus* and *Parichthyocrinus,* and I arranged it on the plate with the latter purely on the ground of superficial resemblance, as the lack of knowledge of the anal structures precluded any decisive comparison. Both of these genera, so far as known, ended with the Keokuk, and from there to the Coal Measures seemed a long leap without any vestige of these forms among the abundant collections from the intervening Kaskaskia. The subsequent discovery of *Amphicrinus* from the British rocks, in a horizon substantially equivalent to the Kaskaskia, suggested a new possibility, and the study of Mr. Wright's series of specimens leaves no doubt that the Kansas fossil belongs to the same genus. This determination fits the case beautifully upon stratigraphic grounds, as the Hurlet limestone shades into the Coal Measures; and it is to be hoped that some of our collectors in the Pennsylvanian area may find a complete specimen by which it may be confirmed.

Of specific characters not much can be said, the narrow and rather angular distal arm branches of the present form being the only one noticeable. The specimen occurred in a thin layer of shale, where it was vertically crushed to a flattened mass, of which the disintegrated remnants of the calyx minus the base and primibrachs constitute one side, and the infolded arms, fairly intact, the other. From what is preserved of the distal portion of the rays (Pl. LX, fig. 12*b*), the arms appear to be rather short, tapering to thin, sharp-backed finials; they are closely abutting, with a somewhat unequal branching toward the end. The lowest bifurcation seen in this view is evidently the third, so that the scattered calyx-plates lying upon the opposite side (fig. 12*a*) are probably chiefly secundibrachs. The lateral faces of these show very plainly the strong ligament fossae for attachment of interbrachials, and several such plates can be recognized. These are all below the level of the tertibrachs, and it is clearly evident that the rays, and perhaps in part their first divisions, abutted closely above them. The sutures in the visible parts of the rays are strongly arcuate.

*Type.* In the author's collection.

*Horizon and locality.* Lower Coal Measures, Pennsylvanian; Girard, Kansas.

# Suborder TAXOCRINOIDEA

## Family TAXOCRINIDAE Wachsmuth emend. Springer

Taxocrinoidea with posterior interradius always differentiated and occupied by anal plates in a tube-like series, none of which are incorporated in the calyx. All anal plates from posterior basal up separated by perisome from adjacent brachials at one or both sides. Distal face of posterior basal not suturally connected with anal plate. Rays above radials partly or wholly separated all around. Crown usually elongate.

### Analysis of the Genera

I. *RA in lower positions.*
Arms dichotomous.
Rays wholly separated by iBr or perisome.
RA in form of R, under r. post. R.
iBr few. IBr 2 ...................... Protaxocrinus.
RA rhombic, obliquely to lower left of r. post. R.
iBr few. IBr 2 or 3 ................. Gnorimocrinus.
II. *RA, if present, only in upper oblique position.*
Arms dichotomous.
Rays wholly separated by iBr or perisome.
iBr variable, usually few. IBr 2 ....................... Eutaxocrinus.
iBr frequently numerous. IBr 3 .......................... Taxocrinus.
Rays abutting above iBr. IBr 3 ................... Parichthyocrinus.
Arms heterotomous.
10 main trunks with ramules. IBr 3 to 6 .................. Onychocrinus.

This is the sole family of the suborder Taxocrinidae, and its chief character is the weak calyx with anal tube originating on the posterior basal, as fully explained in the chapter on Classification. Associated with this character is the usually elongate crown, of which the rays are always partly or wholly separated above the radials by interbrachial plates or perisome; and the arms are usually more or less divergent. There is no genus of this family with completely interlocking rays such as are found in the Lecanocrinidae and Ichthyocrinidae, and only one, *Parichthyocrinus,* in which they abut or interlock at all. That genus has a decidedly different facies from the others of the family, and upon the ground of superficial resemblance might well have been placed among the Ichthyocrinidae, towards which it also tends in the frequently reduced size of the infrabasals. It is an intermediate type, and belongs among the Taxocrinidae as now understood because its first anal plate is a part of the tube, and not of the calyx wall. The large size of the radials will distinguish it from any of the Ichthyocrinidae.

The infrabasals in this family are about as in the Sagenocrinidae, with occasional reduction in size to such a degree that they do not appear beyond the column. The posterior basal throughout is elongated much beyond the size of its fellows, forming the support of the more or less symmetrically placed anal tube. Along with the anal tube the two earlier forms of radianal are found in the pre-Devonian genera; and its migration to a higher position, if that is what occurred, or its complete elimination, is strongly illustrated in the Devonian and Carboniferous genera. There is of course no room here for forms without any anal plate. In the brachial system there is a very regular progressive development from two primibrachs in the Ordovician and Silurian to three or more in the Carboniferous. The change took place in the Devonian, where both forms occurred with occasional variability within the same species.

The Taxocrinidae were the earliest of the Flexibilia in time, beginning in the Ordovician with *Protaxocrinus,* which stands in very close relation to certain Inadunate forms of that age. The family is represented in the Silurian by three genera, and in the Devonian by three, two of which pass into the Carboniferous; but it is preëminently a Carboniferous type, culminating in the strong genus *Taxocrinus* and the highly specialized *Onychocrinus,* both of which continued with numerous species until the close of the Lower Carboniferous.

All of the genera, with the exception of *Parichthyocrinus,* are common to both Europe and America.

### *Geological and Geographical Distribution*

**Number of known species**

(Open figures indicate American, those marked ( ) European)

| Formation | | | Taxocrinidae | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| General | American | Approximate European Equivalents | Protaxocrinus | Gnorimocrinus | Eutaxocrinus | Taxocrinus | Parichthyocrinus | Onychocrinus | Total |
| Lower Carboniferous | Kaskaskia | Hurlet | ... | ... | ... | 2 | ... | 2<br>(1) | |
| | St. Louis | .......... | ... | ... | ... | 1 | ... | 1 | |
| | Warsaw | Middle Carb. | ... | ... | ... | 1 | ... | ...<br>(1) | |
| | Keokuk | .......... | ... | ... | ... | 3 | 3 | 3 | |
| | Burlington | Mountain limestone | ... | ... | ... | 4<br>(2) | 1 | 2 | |
| | Kinderhook-Waverly | | ... | ... | 2 | 3 | ... | ... | 32 |
| Devonian | Chemung | Upper | ... | ... | 5 | ...<br>(2) | ... | ... | |
| | Hamilton | Middle | ... | ... | 2<br>(3) | 3 | ... | ... | |
| | Helderbergian | Lower | 1 | ... | ...<br>(3) | ... | ... | ... | 19 |
| Silurian | Niagaran | Wenlock | 1<br>(3) | 2<br>(1) | ...<br>(1) | ... | ... | ... | |
| | Medinan | .......... | 1 | ... | ... | ... | ... | ... | 9 |
| Ordovician | Trenton | Caradoc | 2 | ... | ... | ... | ... | ... | 2 |
| | American species | 45 | 5 | 2 | 9 | 17 | 4 | 8 | |
| | European species | (17) | (3) | (1) | (7) | (4) | ... | (2) | |
| | Total species | 62 | 8 | 3 | 16 | 21 | 4 | 10 | 62 |

## **PROTAXOCRINUS** Springer

*Plates XLV, XLVI*

*Protaxocrinus* Springer, Jour. Geol., XIV, 1906, pp. 515, 519.—Zittel-Eastman, Textbook Paleontology, 1913, p. 205.

*Lecanocrinus,* Billings (not Hall), Geol. Surv. Canada (Can. Organ. Remains), Decade IV, 1859, p. 46.

*Taxocrinus,* Angelin (in part), Icon. Crin. Sueciae, 1878, p. 8.

*Taxocrinus* (*Gnorimocrinus*) Wachsmuth and Springer (in part), Revision Paleocrinoidea, pt. 1, 1879, p. 50.

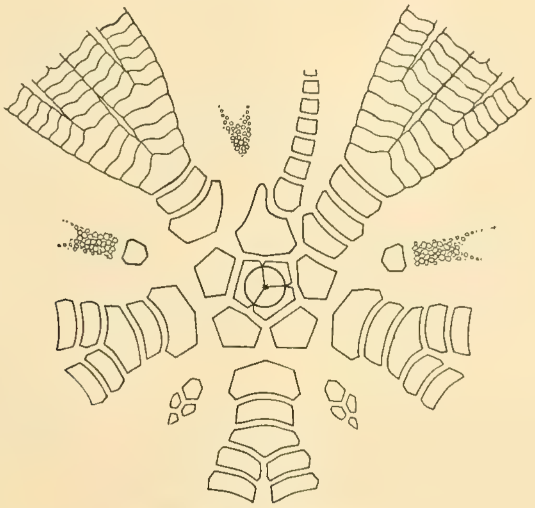

FIG. 46. *Protaxocrinus*

Taxocrinidae with rays usually not abutting over interbrachials. Crown elongate. Infrabasals low, taking small part in calyx wall. Posterior basal elongate. Radianal in primitive position as infer-radial directly under right posterior radial. Anal tube-plates tending to sutural connection with right posterior ray. Interbrachials few, or wanting; lower part of interbrachial areas occupied by plates, or perisome, sometimes not appearing externally. Primibrachs two. Arms dichotomous, divergent. Column slightly enlarging next to calyx.

*Genotype. Taxocrinus ovalis* Angelin.

*Distribution.* Ordovician, Silurian and Devonian; Gotland, the United States, and Canada.

This genus includes the earliest known forms of the Crinoidea Flexibilia. It was proposed by me in 1906 to receive those species with the most primitive anal structure—that is, the radianal in form of a radial at the base of the right posterior ray; among them are several of Angelin's *Taxocrini* which Wachsmuth and Springer had separated under *Gnorimocrinus.* At that time I was not fully aware of the structure of Billings's species *Lecanocrinus elegans* and *L. laevis,* which are now seen to belong here and which carry the genus back to the early Ordovician. Here we have in these two species, when compared with the Inadunate genus *Cupulocrinus* from the same horizon and locality, a fairly close approach to the point of divergence of the Flexibilia from the Inadunates, as already discussed. They show a marked difference in habitus from the Silurian species in the condition of the infrabasals, which are often large, erect, and form part of the calyx wall; this also represents a more primitive stage, judging by analogy from the development of the basals in the existing crinoids. The position of the radianal is a thoroughly diagnostic character, by which the genus is sharply differentiated as a homogeneous unit. In addition to Gotland, the genus has now been found in five localities in America, two in the Ordovician, two in the Silurian, and one in the earliest Devonian. Eight species are recognized, which may be arranged as follows:

### The Species of Protaxocrinus

- I. Br with smooth lateral margins.
  - IBB large and erect.
    - Br angular at dorsal side.
      - IIBr 5 ........................................................ *P. elegans.*
    - Br evenly rounded.
      - Br short and wide.
        - Crown rather robust. Anal tube strong.
          - IIBr 3 or 4, exceptionally 5 .................................. *P. laevis*
      - Br more elongate.
        - Crown slender. Anal tube narrow.
          - IIBr 5 or 6, exceptionally 4 ................................ *P. girardeau*
  - IBB low usually slightly exposed beyond column.
    - IIBr 3.
      - Br evenly rounded.
        - Arms heavy, tapering little .................................... *P. robustus.*
        - Arms more slender, tapering rapidly ........................ *P. virginiensis.*
- II. Br with angular buttresses at lateral margins.
  - Lateral margins sharply angular.
    - Arms ornamented with longitudinal ridges.
      - IIBr 4 or more ....................................... *P. interbrachiatus.*
    - Arms smooth.
      - IIBr 4 ........................................................ *P. ovalis.*
  - Lateral margins but slightly angular or smooth.
    - Arms ornamented with small nodes.
      - IIBr 3 ........................................................ *P. salteri.*

## **Protaxocrinus elegans** (Billings)

*Plate XLV, fig. 1*

*Lecanocrinus elegans* Billings, Rep. Geol. Surv. Canada, 1853-56 [1857], p. 278; Geol. Surv. Canada (Can. Organ. Remains), Decade IV, 1859, p. 47, pl. 4, figs. 4*a*, *b*.

*Taxocrinus elegans,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 3, 1886, pp. 144, 201; Springer, Jour. Geology, XIV, 1906, p. 487.

*Protaxocrinus elegans,* Springer, Geol. Surv. Canada, Mem. No. 15P, 1911, p. 11.

A relatively large species. Crown elongate, with long, slender arms, widest about the upper IIBr. Rays prominent, angular at dorsal side, with lateral margins straight. iBr areas depressed. Calyx narrow, height to width at IAx, 1.6 to 1; height to width of crown, 5 to 1; spread of calyx from base, 1 to 2.3. Surface smooth. Base flush with column facet. Dimensions of type and only known specimen; height of crown to infolding arms, 35 mm.; width at IAx, 7; width at base, 3; height of calyx to top of iBr, 11 mm.

IBB large, erect, forming part of calyx wall. BB the largest plates in calyx. RR and succeeding Br sharply arched and angular, becoming more rounded above, and somewhat flattened distally; height to width of IBr, 3 to 2.5. iBr one, large, followed by two small plates, and others above tapering to a point above which the rays meet closely as far as the IIIBr. No iIIBr. IIBr 5, about as wide as long, with straight sutures. Higher brachials to third bifurcation wider than long, the sutures becoming sharply arcuate distally. Column at base of calyx as large as infrabasal disk, diminishing distally, and columnals gradually increasing in length. Anal structures not disclosed by the specimen, but no doubt as in *P. laevis*.

No specimen but the type has been found that is clearly referable to this species as above defined. All others similar to it found in Canada are smaller, and have been referred to *P. laevis*. A marked peculiarity in the original specimen is a distal flattening of the arms above the last bifurcation, with a sort of longitudinal depression which gives the arm at this point a superficial appearance of being biserial, or of having a median groove as on the ventral side. The latter interpretation was put upon it by Wachsmuth and Springer (Rev. Pal., pt. 3, p. 201), who considered it as a recurrent ambulacrum like that of *Hybocystis*, and this was thought to be present also in *P. laevis*. Careful examination of the type and eight other specimens of *laevis* fails to disclose any such structure as in the type of *elegans*. In the latter it certainly has much the appearance of a recurrent ambulacral groove, as before supposed, but there is no trace of covering plates, or of the sockets for them. After comparison with many specimens of *Hybocystis* in which ambulacra of that kind are well preserved, I think this must be treated as merely a superficial resemblance due to the sharp median curvature of the sinuous sutures, combined with some flattening of the arms.

The arms, though not fully preserved, apparently taper to fine distal ends as in *P. laevis* (Pl. XLV, fig. 4*b*), which is inconsistent with the idea of recurrent ambulacra as I have heretofore described and figured them (Geol. Surv. Canada, Mem. No. 15P, 1911, pl. 2). However caused, this appearance may be a specific character of *P. elegans*. A marked character of the species is the large and erect infrabasals, which it shares with *laevis*, and in which it resembles the Lecanocrinidae division of the Sagenocrinoidea. The general outline of the two species is also strongly similar to that of certain Dendrocrinidae. The type of *P. elegans* is much flattened, giving it a much broader appearance than the real form as shown by measurements from which the dimensions above given are taken.

*Type*. In the Victoria Memorial Museum of the Geological Survey of Canada, Ottawa.

*Horizon and locality*. Ordovician, Trenton limestone; Ottawa, Canada.

### **Protaxocrinus laevis** (Billings)

*Plate XLV, figs. 2-7*

*Lecanocrinus laevis* Billings, Rep. Geol. Surv. Canada, 1853-56 [1857], p. 278; Geol. Surv. Canada (Can. Organ. Remains), Decade IV, 1859, p. 47, pl. 4, fig. 3*a*.

*Taxocrinus laevis,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 3, 1886, pp. 144, 201.—Springer, Jour. Geology, XIV, 1906, p. 487.

*Protaxocrinus laevis,* Springer, Geol. Surv. Canada, Mem. No. 15P, 1911, p. 11, pl. 3, figs. 10, 11*a, b*.

In general form similar to *P. elegans,* but smaller and proportionally shorter and broader, with evenly rounded instead of angular brachials, and secundibrachs usually less than 5. Crown widest about the upper IIBr. A well-preserved specimen of nearly maximum size has the following dimensions: height of crown, 24 mm.; of calyx at top of IAx, 10 mm.; width of calyx, 6 mm.; of base, 2.3 mm. In addition to the characters shown by *P. elegans,* we now have those of the anal side.

Posterior basal larger than others. RA of about the size, form and position of RR in other rays. Anal tube large, with a series of large plates rising from the right shoulder of the basal, suturally connected for some distance with the right posterior ray but entirely free at the left side, where the margin of the left posterior ray is smooth and rounded, and the large anal series is bordered by smaller plates passing into perisome. Rays branching three times, then infolding, with very long and slender finials coiling several times. Column about as in *P. elegans,* sometimes tapering but little.

Billings in describing this species noted its similarity to *P. elegans,* and relied solely on the number of secundibrachs to separate them. This was plain enough in the type specimens, which were all he had of each species. Of *P. laevis,* however, I now have eight additional specimens, and they exhibit such variation in this character as to make it less definite than he supposed, although the preponderance is toward the smaller number in conformity with the generally shorter and broader habitus of the species. In 39 exposed rami of seven of these, the number of IIBr is 2 in 1 ramus; 3 in 6; 4 in 19; 5 in 13. In the eighth (Pl. XLV, figs. 4*a, b*) there are 5 IIBr in 7 out of the 10 rami, and I was at first disposed to place it under *P. elegans* on that account. But it wholly lacks the dorsal angularity of the lower brachials, and even with its equal number of secundibrachs it is a shorter and broader form, the measurements above given being taken from it.

These two species are the earliest known Flexibilia. Neither of the types showed the structure of the anal side, and their true characters have remained in doubt until recently, when several excellent specimens of *P. laevis* came to light showing the anal structure to be of the most primitive type. The close relation of these species to certain Inadunate forms has already been pointed out.

Besides the type I have figured five specimens of various sizes from three localities, which show no material variation.

*Type.* In the Victoria Memorial Museum of the Geological Survey of Canada, Ottawa. The other specimens figured are in the author's collection.

*Horizon and locality.* Ordovician, Trenton limestone; Ottawa and Kirkfield, Canada.

### **Protaxocrinus girardeau** n. sp.

*Plate XLV, fig. 8*

A small species, having the habitus of *P. laevis,* from which it differs by only slight modifications. The calyx and arms are rather more slender, basals and brachials more elongate than in the typical form of that species, and it resembles the exceptional cases rather than the type in having mostly five IIBr. iBr few and small (perhaps only one) followed by perisome. Anal tube narrow and delicate. The column is exactly like that of *P. elegans.* Dimensions of largest specimen: height of crown, 17 mm.; of calyx at top of IAx, 9 mm.; width of calyx, 5 mm.; of base, 25 mm.

When this species was proposed the specimen figured on Plate XLV, from the Girardeau limestone at Thebes, Illinois, was the only one known; since that time, and too late for figuring, a second specimen has been found from the same horizon in Missouri, which is in every way confirmatory of the type. The very close affinity of this Silurian form with the primitive species of the Trenton affords a striking illustration of the reappearance of types in these rocks after a long geological interval. The fact is well recognized that many scarcely distinguishable descendants of Trenton species which are entirely absent in the Cincinnatian appear in the succeeding formations, and that in the Richmond and Girardeau beds there is a recurrence of faunas consisting of species which find their nearest relatives, not in the immediately antecedent Maysville or Lorraine, but among the typical Trenton faunas.

*Type.* In the author's collection.

*Horizon and locality.* Silurian, Girardeau limestone; Thebes, Illinois, and Cape Girardeau, Missouri.

### **Protaxocrinus robustus** n. sp.

*Plate XLV, figs. 9-11*

A robust species, with heavy arms tapering but little. Base expanding rather suddenly from column facet. Arms broadly and deeply rounded. Crown widest about IIBr$_3$, where height to width is about 1.8 to 1; calyx at top of IAx, 1.1 to 1; spread from base, 1 to 3. Height of crown of maximum specimen, 21 mm.; width, 12 mm. Surface smooth.

IBB low, often not exposed beyond the column. IBr increasing in width upward. IIBr 3, without exception in three specimens. Lower Br with straight sutures, becoming slightly arcuate distally. iBr few and small. RA much smaller than RR in other rays. Anal series slender, not adhering to right posterior ray. Column facet as large as infrabasal ring.

This Niagaran representative of the genus shows a constant difference from the Ordovician species in the lower IBB, and shorter, heavier rays. Three specimens of it were found at the same locality in Tennessee showing little variation; one of them, though small, being in very perfect condition. In the short, robust habitus this species is very close to *P. ovalis* of Gotland.

*Types.* In the author's collection.

*Horizon and locality.* Silurian, Niagaran Group, Brownsport limestone, Beech River formation; near Decaturville, Tennessee.

### **Protaxocrinus virginiensis** n. sp.

*Plate XLV, fig. 12*

Of the same habitus as the last species, but with thinner and more rapidly tapering arms.

The species is proposed for a well-preserved specimen from a later horizon than the preceding. The character given for its separation is not very decisive, but considering the difference in horizon and locality, it is probably a good species. Some of the Helderbergian crinoids have a strong general similarity to those of the late Niagaran, but they are in no case actually identical.

*Type*. The author's collection.

*Horizon and locality*. Devonian, Keyser formation of the Helderbergian; Keyser, West Virginia, associated with *Pycnosaccus tenuibrachiatus*.

### **Protaxocrinus interbrachiatus** (Angelin)

*Plate XLV, figs. 13-16*

*Taxocrinus interbrachiatus* Angelin, Icon. Crin. Sueciae, 1878, p. 8, pl. 20, figs. 9, 10.

*Taxocrinus* (*Gnorimocrinus*) *interbrachiatus,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 50.

*Protaxocrinus interbrachiatus,* Springer, Jour. Geology, XIV, 1906, p. 515.

A large species. Crown robust, elongate ovate, widest about $IIIBr_3$, where the interbrachials pass into the tegmen. Height to width of crown, 2.1 to 1; of calyx at top of IAx, 1 to 1.4; spread of calyx from base, 1 to 2.4, chiefly above level of BB. Lateral margins of brachials in lower half of rays angular, forming sharp, conspicuous buttresses with which the perisome connects at their inner margin. Arms broadly rounded or sometimes slightly angular, ornamented distally with longitudinal ridges on each brachial. Base flush with top columnal, and calyx expanding suddenly. Height of crown of large specimen, 40 mm.; width, 16 mm.; width of base, 5 mm.

IBB low, slightly visible above the column. BB forming a funnel continuous with column. RR the largest plates of calyx, causing a rather pronounced expansion at their level. Anal tube strong, with first two or three large plates attached to r. post. ray. RA smaller than corresponding RR. iBr consisting of one to three well-defined plates followed by a profuse development of perisome in the first and second axils. IIBr 4 or occasionally more. IIIBr 7 to 9 outer, 5 or 6 inner; IVBr 13 to 15 outer, 8 to 10 inner. Arms strong, tapering slowly, infolding above the fourth bifurcation. Brachials generally wider than high, and sutures for the most part straight, without distinct sinuosity. Column strong, with proximal columnals as broad as the base; gradually diminishing in width downward.

The most striking characters of this Swedish species are the lateral buttress-like angularities of the brachials, and the profuse development of plated perisome as far as the second axil. These are finely shown by the figures made from various specimens in the museum at

Stockholm. Looking at the angular inner margin of the left posterior ray in a specimen like that of figure 14*a*, Plate XLV, it would seem contrary to the rule we have stated for the structure of the anal side in the Taxocrinidae; but it is evident from that and other figures that these marginal angularities were not for sutural attachment of solid plates, but were merely ornamental. The spaces opposite them are actually occupied by perisome which is attached at the inner margin of the plates; and the same angularities are seen on the higher brachials where neither interbrachials nor perisome are present.

The ornament on the brachials in the form of disconnected longitudinal ridges or wrinkles is quite distinct for the species. Angelin's figures were made from two specimens, from both of which I give new and more detailed figures. Two other fragments have furnished fine enlarged drawings of the interbrachial spaces (Pl. XLV, figs. 15, 16); in the first may be seen some of the coiled arms toward the distal end, showing how extremely slender they become.

*Types.* In the Riks Museum, Stockholm, Sweden.

*Horizon and locality.* Silurian, Wenlock Group (horizon *f*); Follingbo, Island of Gotland.

### **Protaxocrinus ovalis** (Angelin)

*Plate XLVI, figs. 8-11*

*Taxocrinus ovalis* Angelin, Icon. Crin. Sueciae, 1878, p. 8, pl. 20, figs. 13, 14.

*Taxocrinus* (*Gnorimocrinus*) *ovalis,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 51.

*Protaxocrinus ovalis,* Springer, Jour. Geology, XIV, 1906, p. 515.

Type of the genus.

A small species, similar to *P. interbrachiatus* and perhaps only the young of that species; agreeing with it closely except in the shorter, wider habitus, better definition of iBr plates, and the absence of ornament on the arms. In that case however, the former species would become the synonym, and *P. ovalis* would stand, being the first on the page of Angelin's descriptions. In the preservation in which these fossils are often found the absence of such ornament may be misleading. A maximum specimen gives the following proportions: height to width of crown, 1.7 to 1; calyx to top of IAx, 1 to 1.7; spread of calyx, 1 to 2.2. Height, 17 mm.; width, 10 mm.; base, 4 mm. The first interbrachial plate is relatively larger in these specimens, but the development of perisome is entirely like that of *P. interbrachiatus.*

*Types.* Riks Museum, Stockholm, Sweden.

*Horizon and locality.* Silurian, Wenlock Group (horizon *f*); Follingbo and Sigdes, Island of Gotland.

### **Protaxocrinus salteri** (Angelin)

*Plate XLVI, figs. 1-7*

*Taxocrinus salteri* Angelin, Icon. Crin. Sueciae, 1878, p. 9, pl. 23, figs. 1, *1a*.

*Taxocrinus* (*Gnorimocrinus*) *salteri*, Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 51.

*Protaxocrinus salteri*, Springer, Jour. Geology, XIV, 1906, p. 515.

*Taxocrinus distensus* Angelin, Icon. Crin. Sueciae, 1878, p. 9, pl. 26, figs. 7, *7a*.

*Taxocrinus tubuliferus* Angelin, *ibid.*, p. 9, pl. 20, figs. 11, 12.

*Taxocrinus austini* Angelin, *ibid.*, p. 9, pl. 19, figs. 11, *11a*.

A medium sized species. Crown elongate, widest about $IIIBr_5$, where height to width is 1.8 to 1; calyx at top of IAx, 1 to 1.3; spread of calyx from base to same level, 1 to 2.5. Lateral margins of brachials slightly angular, or smooth. Arms broadly rounded, tapering but little to the fourth bifurcation; ornamented with small nodes or pustules. Small iBr, followed by perisome in first and second axil. Anal tube small. IIBr 3, exceptionally 4. Column as large as the base, tapering but little downward. Height of large specimen, 41 mm.; width, 23 mm.; base at column facet, 6 mm.

This species is similar in general form to *P. interbrachiatus*, but is more slender below, and differs in the pustulate ornament on the arms, fewer IIBr and smaller anal tube. In addition to Angelin's type I have figured another similar but somewhat larger specimen showing the anal side, with various details from both showing ornament and interbrachial structures. Both these are from Faro. I have also placed under this species several specimens from other Gotland localities which are not so characteristic. Among these are: (1) The type of Angelin's *Taxocrinus distensus* (Pl. XLVI, figs. *3a, b*); it has but two plates below the axillary in the right posterior ray, as in the others, and would thus seem to be without a radianal. But the small size of the first plate shows that it is the radianal, and that the specimen is abnormal in lacking the super-radial or $IBr_1$, a defect which is compensated by the addition of an extra IIBr. Allowing for this it agrees well with the type. (2) The type of *Taxocrinus tubuliferus* (Pl. XLVI, figs. *5a, b*), a very young specimen. (3) The type of *Taxocrinus austini* (Pl. XLVI, figs. *6a-d*), another very young, imperfect and distorted specimen, wholly destitute of any diagnostic characters for specific description. (4) A fine specimen from Follingbo (Pl. XLVI, fig. 4) abnormal in having but one IBr in the left posterior ray, which is compensated by extra IIBr following it. All these agree well enough with the species in the absence of marked angularity on the margins of the rays, and the presence of 3 IIBr in a decided preponderance of the rami. The remaining specimen (Pl. XLVI, fig. 7), with 4 IIBr in all three of the visible rami, must be considered a strong variant of the species.

It is difficult to state diagnostic characters which will consistently differentiate this and the two preceding species, and it is possible that all three should be placed together as a variable species with 3 and 4 IIBr under the name *P. ovalis*.

*Types.* Riks Museum, Stockholm, Sweden.

*Horizon and locality.* Silurian, Wenlock Group, horizons *d* and *f;* Faro, Follingbo, Wisby, Djeywick and Endre, all in the Island of Gotland.

## **GNORIMOCRINUS** Wachsmuth and Springer

*Plate XLVII, figs. 1-17*

*Gnorimocrinus* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 50; Proc. Acad. Nat. Sci. Philadelphia, 1890, p. 388.—Zittel-Eastman, Textbook Palaeontology, 1896, p. 163 (2d Ed., 1913, p. 205).—Bather, Rep. British Assoc. for 1898 [1899], p. 923; Treatise on Zoology (Lankester), pt. 3, 1900, p. 189.—Springer, Jour. Geology, XIV, 1906, p. 515.

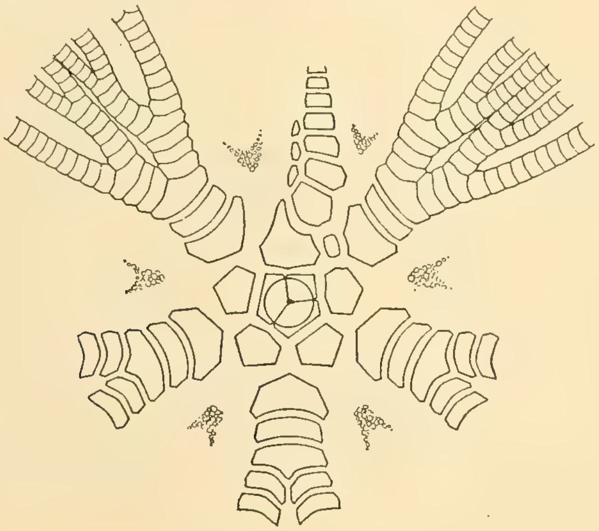

FIG. 47. *Gnorimocrinus*

Taxocrinidae with rays not abutting above interbrachial areas. Crown rather low and rotund. Infrabasals low, usually exposed, forming small part of calyx wall. Posterior basal elongate. Radianal rhombic, obliquely to lower left of right posterior radial. Interbrachials few or usually wanting, and areas filled with perisome. Primibrachs two. Arms dichotomous, divergent. Column short, not enlarging next to calyx, terminating in a branched root.

*Genotype.* *Taxocrinus expansus* Angelin.

*Distribution.* Silurian; Gotland and the United States.

*Gnorimocrinus* was proposed by Wachsmuth and Springer as a subgenus to receive all of Angelin's Silurian *Taxocrini,* with the Devonian *Zeacrinus excavatus* of Schultze added. From the diagnosis the chief character on which the separation from *Taxocrinus* was based is clear, as shown by the following extract: "Figure irregular, lacking the bilateral symmetry of that genus. The basal on the posterior side is exceedingly large, reaching almost to the top of the adjoining first radials. The first anal plate, instead of resting upon the truncated upper side of that basal, leans against the oblique right side and the adjoining first radial." That is to say, in present terminology, it has the radianal obliquely below the right posterior radial. That this was the one thing relied upon is emphasized by the note in the Revision of the Palaeocrinoidea, pt. 1, p. 50, under *G. distensus:* "In this species, as also *G. punctatus,* the irregular arrangement of the anal area is not sufficiently shown in the figures." My investigation of this group in 1906 led to the recognition of two kinds of irregularity in the anal side worthy of generic distinction, viz.: (1) where the radianal is in the form and position of a radial, under the right posterior ray; and (2) where it has been lifted out of the ray, or reduced to a small quadrangular plate obliquely to the left of the radial.

The definition as quoted above clearly refers to the latter, and was evidently taken from *G. expansus,* in which the structure is very plainly shown by Angelin's figure. The list of species, however, included a considerable number of species having form No. 1, and some in which the irregularity was not in the possession of a radianal, but in the asymmetric position of the first plate of the tube, which we know now to be characteristic of all the Taxocrinidae. No type species was indicated by the authors, but Bather in 1899 (Rep. Brit. Association, p. 923) supplied this defect by proposing *G. expansus,* which thus becomes the type by subsequent designation. It happens that this is the only one of the species listed which has the character described, and the curious result follows that out of the twelve species originally referred to the genus, only a single one remains under it now. But subsequent discoveries in the American Silurian have added new species, which confirm the validity of the genus and greatly extend its geographic range. Those species having structure No. 1, as already seen, have been transferred to *Protaxocrinus. G. excavatus* goes very readily under *Dactylocrinus; G. loveni* to the new genus *Meristocrinus;* and *G. oblongatus,* with its synonym *G. rigens* to *Eutaxocrinus. G.* (*Taxocrinus*) *punctatus* is insufficiently defined, and the original cannot be found; it is probably a Cyathocrinoid.

While the excavate posterior basal followed by an anal tube suturally free at one side fixes the generic position of this form without doubt among the Taxocrinidae, it is not easy to draw a satisfactory line between it and the Lecanocrinoid genus *Asaphocrinus,* because of intermediate stages exhibited by that genus, and by abnormal specimens of *G. expansus* tending to vary in that direction. The species of the two genera must be considered as in the borderland between their families. *Gnorimocrinus* is exclusively a Silurian genus; the three following species are recognized:

### The Species of Gnorimocrinus

I. Arms short, heavy throughout, rounded, tapering little.
    Br with lateral angles or buttresses.
        Specimens small. IIBr 3 (or 2) ................................ *G. expansus.*
    Br with lateral margins smooth.
        Specimens larger. IIBr 3 (exceptionally 2) ........................ *G. cirrifer.*
II. Arms tapering rapidly to the branches.
    RR large and more prominent than succeeding IBr. IIBr 2 or 3 ......... *G. varians.*

## **Gnorimocrinus expansus** (Angelin)

*Plate XLVII, figs. 1-6*

*Taxocrinus expansus* Angelin, Icon. Crin. Sueciae, 1878, p. 9, pl. 20, figs. 15, 16.

*Taxocrinus* (*Gnorimocrinus*) *expansus,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 50.

*Gnorimocrinus expansus,* Bather, Rep. British Assoc. for 1898 [1899], p. 923; Treatise on Zoology (Lankester), pt. 3, 1900, p. 189.—Springer, Jour. Geology, XIV, 1906, p. 515.

Type of the genus.

A small species. Crown short, broad, rotund, infolding about the third bifurcation, widest about IIBr 2 or 3. Height to width at that level, 1 to 1; of calyx to top of axillary IBr, 1 to 1.4; expanding rapidly from BB with spread from base 1 to 5. IBr almost filling the distal face of RR and succeeding them without any conspicuous difference in width. Anal tube very large, resembling a ray. Arms heavy throughout, tapering but little; lateral margins of brachials projecting in angular buttresses. Surface smooth. Dimensions of an average specimen: crown, 10 mm. high by 10 wide; base, 2 mm.; calyx to IAx, 5 mm.; width, 8 mm. Maximum specimen, 17 mm. high.

IBB low, slightly visible beyond the column. BB small except post. B which is large, rising to height of RR. RR the largest plates in the calyx, expanding abruptly from the base. IBr short and about as wide as RR, leaving narrow iBr spaces; IIBr 3 or 2; these and higher Br about twice as wide as high; not over three bifurcations visible. RA very small, rhombic; anal $x$ much larger, followed by still larger plates in series, the first one or two suturally connected with ray at right side. iBr areas occupied by thin perisome with scattered granules. Column large, facet as large as IBB circlet.

Out of six specimens, all from Follingbo, four are of about the size stated above as the average, and two are about one-half larger. One of the former (Pl. XLVII, fig. 6) is abnormal in having a pentagonal RA touching IBB in line with BB; and one of the latter (fig. 5) in having the large tube median in position, with its lower plate suturally united to the rays at both sides. Figure 1 is a new drawing of Angelin's original, and the others are from specimens found since; two of them show the interbrachial perisome in strong enlargement, with the calcareous granules well separated.

*Types.* All in the Riks Museum, Stockholm.

*Horizon and locality.* Silurian, Wenlock Group, horizon *f;* Follingbo, Island of *Gotland.*

### **Gnorimocrinus cirrifer** n. sp.

*Plate XLVII, figs. 7-12*

A larger species than the preceding. Crown short, wide, rotund, with widely divergent arms, infolding after third bifurcation; widest about $IIBr_3$, where height to width is 1 to 1.3. Calyx broadly and evenly expanding from base to $IIBr_2$, where height to width is 1 to 2, and spread from base, 1 to 4. Lateral margins of brachials smooth; anal tube and arms more slender than in the last species, but rounded, and tapering but little. Surface smooth. In a mature specimen the crown is 17 mm. high and 22 mm. wide; base, 4 mm. Small specimen, 8 mm. high by 9 wide. Column, 38 mm. long to end of root.

IBB scarcely visible beyond column. RR large, rather angular dorsally in mature specimens and followed by IBr nearly as wide, leaving but small shoulders at the sides. iBr spaces wide, owing to the spread of the calyx rather than to the space left at the distal edge of RR; no regular iBr; perisome not preserved, and probably thin. IIBr mostly 3, these and higher Br about one-third wider than long. RA small, square; anal tube of medium size, almost entirely free from the rays. Column short, without proximal enlargement; composed of a few thin ossicles next to the calyx, thence becoming strong, cylindrical, about as long as wide, with some alternation of thinner ones in upper part. Radicular cirri prominent at distal end, sometimes extending with a semblance of regularity half way up the column.

This is a closely similar species to *G. expansus,* but of a more slender habitus. It is the first occurrence of the genus recorded from America, and the material for illustrating it is unusually good, including various stages of growth from mature to very young, where the arms infold at the IIBr (Pl. XLVII, fig. 12). In this specimen, which has a complete stem, the great length of the columnals in the young is well shown, as compared with those of the adult stem in figure 7.

*Type.* Author's collection.

*Horizon and locality.* Silurian, Upper Niagaran Group, Brownsport limestone, Beech River formation; Decaturville, Decatur County, Tennessee.

### **Gnorimocrinus varians** n. sp.

*Plate XLVII, figs. 13-17*

Perhaps only a variant of *G. cirrifer* with which it is associated in the same bed; but it is distinguished by its more tapering, slender arms, relatively large size of RR, and greater difference between them and the succeeding IBr, giving more the appearance of a defined calyx; also by the tendency to reduction in number of IIBr, which in one out of five specimens are 2 all around, and partly so in two. This form is a variation in the direction of the large species from the same formation which has been placed under the Lecanocrinidae as a new genus, *Asaphocrinus,* in some ways closely related to *Gnorimocrinus,* and some of the specimens of the present form may possibly be younger stages of that species.

*Types.* Author's collection.

*Horizon and locality.* Silurian, Upper Niagaran, Brownsport limestone, Beech River formation; Decaturville, Decatur County, Tennessee.

## **EUTAXOCRINUS** Springer

*Plates XLVII, XLVIII, XLIX, L, LXXV*

*Eutaxocrinus* Springer, Jour. Geology, XIV, 1906, pp. 493, 519.—Zittel-Eastman, Textbook Paleontology, 1913, p. 205.

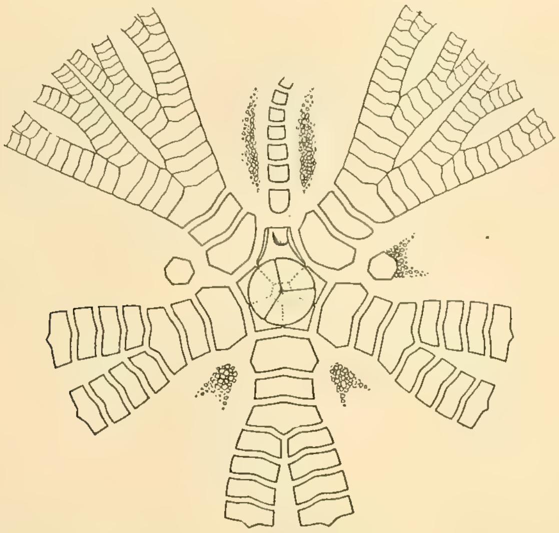

FIG. 48. *Eutaxocrinus*

Taxocrinidae with rays not abutting over interbrachials. Infrabasals low, taking little part in calyx wall. Posterior basal elongate. Radianal, if present, only in upper oblique position. Interbrachials few or none. Primibrachs two. Arms dichotomous, usually more or less divergent. Column usually enlarging next to calyx. Otherwise as in *Taxocrinus.*

*Genotype. Taxocrinus affinis* Müller.

*Distribution.* Silurian to lower part of Lower Carboniferous; Continental Europe, the United States and Canada.

This genus was proposed by me to receive those species of *Taxocrinus* without a radianal in the lower positions and having only two primibrachs. This division has a stratigraphic significance which lends support to its recognition; for whereas the group of species here assembled begins in the Silurian, culminates in the Middle Devonian and ends at the very base of the Lower Carboniferous, the parent genus as it is left after the removal of these species begins in the Devonian, culminates in the middle of the Lower Carboniferous long after the extinction of *Eutaxocrinus,* and continues with characteristic species to the end of that epoch. In other words *Eutaxocrinus* is essentially a Devonian, and *Taxocrinus* essentially a Carboniferous, genus. The separation has proved to be a useful one from the viewpoint of the systematist, because *Taxocrinus,* even after the removal of some other genera on account of the radianal, still remained a somewhat unmanageable genus. The characterization of the species is on the whole satisfactory, and with the exception of one or two which are imperfectly known they are recognized without difficulty.

The Silurian species, *E. oblongatus,* is somewhat aberrant in its arm structure, having transitional features which make its position here not free from doubt. Leaving this out of consideration the remaining species fall into two rather well marked sections, viz.: (1) those without regular interbrachials, and (2) those which have them. In the first there are more or less ample spaces between the rays and their divisions, but these spaces must have been filled with perisome, as we actually find them in *E. juglandiformis,* where the small plates become rather strong and are not far from the stage of interbrachials. In the second, distinct interbrachials appear to a limited extent, but they never become so important as in some of the true *Taxocrini.* As a rule the anal interradius is narrow and the tube small, notable exceptions being *E. juglandiformis* and *E. perplexus.* Sixteen species are recognized, one from the Silurian, thirteen from the Devonian, and two from the base of the Lower Carboniferous, which may be arranged as indicated below. Of the other species described under *Taxocrinus* but resembling this genus in having two IBr, *T. rigens* Angelin is a synonym; *T. priscus* Steininger and *T. gracilis* Meek and Worthen are insufficiently defined; and *T. grebei* Follmann probably does not belong to the Flexibilia.

### THE SPECIES OF EUTAXOCRINUS

I. Arms long, branching very unequally, with strongly modified dichotomy.
iBr few and small.
IIBr 3 .................................................. *E. oblongatus.*
II. Arms branching with ordinary dichotomy.
No iBr.
IIBr 4.
Crown short, turbinate.
Arms broad and short, tapering rapidly.
Surface tubercular ...................................... *E. rhenanus.*
Crown elongate.
Arms stout, tapering gradually.
Surface smooth ......................................... *E. stuertzii.*
Crown elongate, cylindrical.
Arms long, slender, tapering gradually.
Anal interradius very narrow; iBr may occur.............. (?) *E. pulcher.*
IIBr 3 or 4 irregularly.
Crown elongate, turbinate.
Margins of Br not raised.................................. *E. ithacensis.*
Crown short, rotund.
Specimens very small........................................ *E. alpha.*
Specimens medium to large size............................... *E. curtus.*
IIBr usually 3.
Crown elongate, turbinate.
Margins of Br raised....................................... *E. whiteavesi.*
Crown elongate, broad and rotund below.
Rays angular dorsally. iBr spaces narrow.................... *E. eifelensis.*
Rays not angular. iBr spaces wide.
Anal tube wide, composed of very short plates.
RR largest plates in calyx........................... *E. juglandiformis.*

iBr present.
IIBr 4.
Crown short, turbinate.
Arms tapering rapidly.
Anal tube narrow, composed of elongate plates.
iBr prominent and deep.................................*E. affinis.*
Crown elongate, expanding with curved sides.
Arms tapering slowly ..................................(?) *E. amplus.*
IIBr 3 or 2.
Crown rather short, turbinate, base broad.
Arms diminishing rapidly at each bifurcation..................*E. fletcheri.*
Crown more elongate.
Arms tapering gradually ..............................*E. montanensis.*
Exceptional species, with anal tube like *Taxocrinus juglandiformis;*
small iBr, and apparently a radianal........................(?) *E. perplexus.*
Insufficiently defined ................................................*E. gracilis.*

### **Eutaxocrinus oblongatus** (Angelin)

*Plate XLVIII, figs. 1-4*

*Taxocrinus oblongatus* Angelin, Icon. Crin. Sueciae, 1878, p. 8, pl. 20, fig. 17.
*Taxocrinus (Gnorimocrinus) oblongatus,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 51.
*Eutaxocrinus oblongatus,* Springer, Jour. Geology, XIV, 1906, p. 493, [on p. 515, ? *Dactylocrinus*].
*Taxocrinus rigens* Angelin, Icon. Crin. Sueciae, 1878, p. 9, pl. 18, figs. 7, 8.

A large species. Crown elongate, greatly expanding from a broad base and attaining greatest width about the last IIBr, where height to width is 3 to 1. Calyx at top of IAx, 1 to 1.9, spread from base, 1 to 2.7. Anal tube and iBr areas narrow, with few or no iBr. Arms long, gradually tapering, with from 6 to 10 bifurcations; the outer branches of the ray and of each division being larger, and having longer intervals, than the inner. Thus the tendency is toward branching by subordinate ramules, which in turn similarly branch again more than once. Intervals in number of brachials on the outer branches of a ray, beginning above IBr, are 7-6-6-5-5; and on the inner, 5-6-5-5-5-4-4, etc. Sutures broadly arcuate. Surface smooth. Dimensions of complete crown: height, 48 mm.; width, 16.5 mm.; base, 5.5 mm.

IBB low and flat, slightly exposed externally beyond the column. BB small, with distal part long, narrow, tongue-shaped; post. B but little higher than others, and its apex very narrow. RR over twice as large as BB, deeply arcuate below. IBr still wider, and increasing upward. IIBr 3, two-thirds as wide as IBr. Further divisions in about the same relative size, the inner branch about two-thirds as large as the outer. All branches and ramules rounded and strong until they disappear by incurving. Lateral faces of lower brachials projecting in small buttress-like nodes. Anal tube short and narrow, resting in a rounded notch on right sloping shoulder of post. B; in close contact with sides of rays, nearly filling the area, but not suturally connected at left side, and probably not at the right. iBr small and narrow, sometimes not appearing externally. Column unknown.

This species departs from the characters of the genus in its heterotomous arms. Their arrangement is really not very different in principle from that of a great many species which we call dichotomous, in which the outer ramus of the dichotom is slightly the larger, and has longer intervals between bifurcations. Here this has gone so far in the direction of heterotomy such as we have in *Dactylocrinus* that the species might be separated generically on that account. It will not go under *Dactylocrinus* or its allies by reason of the characters of the anal tube and base, and I have preferred to consider it as an early variant of the present genus, of which it is the only Silurian representative. *T. rigens* is clearly a synonym. In addition to Angelin's two types which are refigured (Pl. XLVIII, figs. 1, 2), there are two other specimens showing the anal side, both from Wisby. In some of these there is a curious open space between the infrabasals marked by a distinct notch at the exterior (Pl. XLVIII, figs. *2b*, 4).

*Types.* Riks Museum, Stockholm, Sweden.

*Horizon and locality.* Silurian, Wenlock limestone; Faro and Wisby, Island of Gotland.

### **Eutaxocrinus rhenanus** (C. F. Roemer)

*Plate XLVIII, figs. 5-10*

*Cyathocrinus rhenanus* Roemer, Foss. Fauna Dev. Geb. Rhein., 1851, p. 7, pl. 2, figs. *2a-e;* Verh. Nat. Hist. Ver. preus. Rheinl., VIII, 1851, p. 363, pl. 8, figs. *2a-e*.—Müller, Abhandl. Akad. Wiss. Berlin, 1857, p. 245.

*Taxocrinus rhenanus,* Sandberger and Sandberger, Verst. Rhein. Schicht. Nassau, 1850-56, p. 393, pl. 35, with text-fig., figs. 17, *17a,* not *17b, c.* (*Cyathocrinus* on the plate).—Müller, Monatsber., March 1858, p. 185.—Beyrich, Monatsber. Akad. Wiss. Berlin, 1871, p. 43 (Transl. in Ann. and Mag. Nat. Hist., (4) VII, p. 401).—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 49.—Follmann, Verh. Naturh. Verein, 1882, p. 164 (Unterdev. Schicht. Olkenbach, pp. 36, 38); Unterdev. Crinoiden, 1887, p. 4.

*Cyathocrinus brachydactylus* F. A. Roemer, Palaeontographica XIII, 1866, p. 205, pl. 35, figs. *10a, b.*

A medium-sized species. Crown elongate, with broad base, expanding gradually from the base to about the third bifurcation; widest about the IIIBr, where height to width is about 1.4 to 1; of calyx at top of IBr, 1 to 1.5; spread from base, 1 to 1.8. iBr wanting or small and narrow. Anal structures unknown. Arms strong, rounded, diminishing by nearly half at each bifurcation, and lying close together though not abutting; sutures obscurely arcuate. Surface throughout ornamented with fine tubercles, most prominent on the sides of the arms; on the stem they take the form of crenulation at the edge of the columnals. Dimensions of type specimen: Crown, 33 mm. high by about 23 wide; base, 9 mm.

IBB low, but little visible beyond the column. BB short and wide, with rather obtuse salient angles. Anal side unknown. RR and IBr large, of similar shape, gradually widening upward leaving little space for iBr, which if present must be narrow and elongate. IIBr 4. IIIBr 7 or 8 in the outer divisions, and 5 in the inner. Arms infolding shortly above the third bifurcation. Column robust, commencing flush with the base with very thin columnals, strongly crenulated; tapering gradually for 10 or 12 mm., beyond which it becomes cylindrical and the alternate columnals increase in length.

All the specimens known to me are in the form of impressions from natural moulds left by the decomposition of the fossil in the sandstone matrix. Roemer's excellent figure, which I reproduce on Plate XLVIII, figure 5*a*, is partly restored, and I have given for comparison an accurate figure from a gutta-percha cast of the type specimen (fig. 6). I also figure another smaller specimen, and give copies of three of Sandberger's figures of others. All these are from the Coblentz beds of the Lower Devonian (the Spiriferen-sandstein of the Sandbergers) from various localities in the vicinity of Coblentz. In figure 10, one of Sandberger's specimens, there seem to be rather abundant interbrachials both primary and secondary. The structures are indistinct, but the very short and narrow first primibrach indicates an altogether different type of ray, which does not belong to the species.

None of the specimens expose the anal side, but Dr. Follmann (Unterdev. Crin., 1887, p. 5) describes a specimen from an impression of the base which shows the posterior basal differentiated from the others by having an additional side. In the type there is a peculiar irregular basal which is evidently abnormal. Roemer described the calyx of this species as consisting of basals and radials only, considering the plates which were partly evident below the basals as only an enlargement of the upper stem joint. Johannes Müller (Monatsber. Akad. Wiss. Berlin, 1858, p. 186) pointed out that these plates formed a part of the calyx which could not be ignored, and stated them in his diagnosis as three. This was confirmed by Follmann (1882, p. 165) who on a wax impression of the lower part of the calyx found the 3 IBB plainly visible. The 4 IIBr are quite regular throughout the specimens except figure 9, in which the details are indistinct.

Roemer[1] in 1851 referred to this species a figure by Goldfuss in Petrefact. Germ. plate 58, Figure 6B, under the name *Cyathocrinus tuberculatus,* of a fragmentary specimen from the Grauwacke of the Rheinland, which is clearly excluded by its large interbrachial plate.

*Cyathocrinus brachydactylus,* described by F. A. Roemer upon an imperfect specimen from an equivalent horizon in the Hartz Mountains, is probably this species. It is said to have a similar tubercular ornament, and the general construction is substantially the same.

*Types.* Roemer's original, formerly in the Anatomische Museum, is now in the Museum für Naturkunde, Berlin, Germany.

*Horizon and locality.* Lower Devonian; upper Coblentz beds; Coblentz, Dillenburg, Lahnstein, Olkenbach, and Wittrich on the Rhine; Rammelsburg near Goslar in the Hartz, Germany.

### **Eutaxocrinus stürtzii** (Follmann)

*Plate XLVIII, figs. 11-12*

*Taxocrinus stürtzii* Follmann, Unterdevon. Crinoiden, 1887, p. 6, pl. 1, fig. 3.

A rather large species; with crown elongate and narrow, arms long, rather stout, tapering very slowly to very small finials; and with 4 IIBr. Surface smooth. Column small, enlarging rapidly at the calyx to the diameter of the base; proximal columnals thin in the enlargement, becoming longer and alternating below. IBB low, visible above the column. iBr absent and anal structures unknown. The condition of the specimens does not admit of accurate measurements; the least distorted crown is 36 mm. to near the fourth bifurcation, and probably not over 15 mm. wide.

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[1] Verh. Nat. Hist. Ver Rheinl. VIII, p. 363.

Disregarding the doubtful Silurian species, this is the earliest of the genus; it occurs in the Hunsrück slates, about the middle of the Lower Devonian. The only species with which it needs to be compared is *T. rhenanus* from the next higher formation in the same region, and from that it is readily distinguished by its more slender proportions throughout. This is well shown by the relative proportions of the lower brachials in the two; in *T. rhenanus* the IIBr are, height to width, 1 to 2.1; IIIBr 1.4 to 3; in *T. sturtzii* IIBr are 1 to 1.5; IIIBr 1.8 to 2. The specimens are found crushed very flat, in a dark pyritiferous slate which adheres so closely to the fossils that it is only removed by chemical means, and structural details are obscured. I have copied Follmann's figure of the type, and figured the best other specimen known to me from the collection of Dr. B. Stürtz in Bonn.

*Type.* In the Palaeontological Museum of the Rheinische Friedrich-Wilhelm's University at Bonn, Germany.

*Horizon and locality.* Lower Devonian, Hunsrück slate; Bundenbach, Germany.

### **Eutaxocrinus affinis** (Müller)

*Plate XLIX, figs. 9-10*

*Taxocrinus affinis* Müller, Monatsber. Akad. Wiss. Berlin, 1856, p. 353; *ibid.*, Abhandl. for 1856 [1857], p. 244, pl. 1, figs. 1, 2.—Schultze, Mon. Echinodermen Eifler Kalkes, 1867, p. 34, pl. 4, figs. 2, *2a, b.*—Beyrich, Monatsber. Akad. Wiss. Berlin, 1871, p. 43 (Transl. in Ann. and Mag. Nat. Hist., (4) VII, p. 401).—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 48.

*Eutaxocrinus affinis,* Springer, Jour. Geology, XIV, 1906, p. 519.

Type of the genus.

A medium-sized species. Crown short, turbinate, nearly as wide as high at level of IIIBr in the principal specimen, which is somewhat compressed vertically, being 30 mm. high, 27 mm. wide; base, 7 mm., in natural contour probably about 1.5 high to 1 wide. In the type, which is normal as far as preserved, the calyx shows height to width at top of IBr, 1 to 1.5, and spread from base of 1 to 3, most of this being opposite $IBr_1$ by reason of the large iBr. Side outline slightly convex. Arms broad and flat, diminishing rapidly at the bifurcations beyond the IIBr, and infolding about the fourth; sutures broadly arcuate beyond IBr. Anal tube fairly strong, composed of elongate plates, resting on right shoulder of post. B. iBr present. Surface smooth.

IBB low, appearing as a thin ring above the column. BB small, short, with obtuse salient angles, except the posterior one supporting the anal series. RR small, almost quadrangular; shorter than either IBr, and little more than half the width of the axillary; deeply beveled at the lateral margins. IBr rapidly widening upward, axillary twice as wide as high. IIBr 4, almost as large as the first IBr, and three times as wide as high; higher Br diminishing in width by half, but less in length, not meeting above iBr, but leaving long and wide areas. iBr one large, opposite $IBr_1$, thick, convex or projecting above outer surface of adjacent brachials; areas above probably filled by perisome.

The most striking character of this species is the thick, rounded interbrachials, which resemble blunt pegs standing up between the bases of the rays, unlike those of any other known species; the distal margins of these are rounded, indicating that no solid plates followed them, although the spaces above and between the higher divisions are ample. The whole aspect of the crinoid is different from that of the other Devonian species, as is apparent from a glance at the figures. The best specimen is the one figured by Schultze, now in the Museum of Comparative Zoology, Harvard. His figure shows only two plates in the anal series, but further cleaning of the specimen has developed three more above (Pl. XLIX, fig. 10*b*). I have copied Müller's figures of his type in the Berlin Museum, reducing them to natural size; it is a younger individual than the other, with a more slender calyx, and Müller's figure doubtless shows the anal series located more symmetrically than it really is. The only other specimen known is one in the University of Bonn.

*Types.* Müller's original is in the Anotomische Museum at Berlin; Schultze's in the Museum of Comparative Zoology, Harvard College.

*Horizon and locality.* Middle Devonian, Eifel limestone; Gerolstein and Kerpen, Eifel Mountains, Germany.

### **Eutaxocrinus juglandiformis** (Schultze)

*Plate XLIX, figs. 11-12*

*Taxocrinus juglandiformis* Schultze, Mon. Echinodermen Eifler Kalkes, 1867, p. 35, pl. 4, figs. 4, 4*a*, *b*.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 48.

*Cyathocrinites,* Quenstedt, Handbuch Petrefaktenkunde, 1852, p. 617, pl. 54, fig. 23; *ibid.,* 1885, p. 945, pl. 75, fig. 12.

A medium-sized species. Crown short, broadly rounded below, widest about IIIBr, where height to width is 1.2 to 1. Calyx very low convex, height to width about 1 to 3.6, and spread from base to top of IAx 1 to 3. Height of crown in one of the types 27 mm.; width, 22 mm.; base, 3.6 mm. Arms broad, diminishing rapidly at the bifurcations which extend to four. Sutures straight in lower part, becoming slightly sinuous above. No regular iBr; areas occupied by perisome. Anal tube broad, composed of very short plates. Surface smooth, or slightly wrinkled.

IBB low, forming a flat disk covered by the column and nearly of its diameter. BB low, visible chiefly in a narrow rim outside the column facet, or with small salient points; excepting post. B, which is long and broad, concave distally, supporting a very large anal tube composed of plates four times wider than high, bordered on either side by integument of numerous small convex plates, the arms meeting above them. RR large, longer than either IBr; these are wider than RR, increasing in width upward, as do the IIBr also; subsequent arm divisions little over half the width of those preceding, and enlarging slightly at the axillaries. All brachials from radials to the higher divisions wider than high, the lower ones two or three times. IIBr 3. Column unknown, facet slightly smaller than BB circlet.

This species is well formed for the accommodation of interbrachials, but they have not passed the stage of irregular perisome, in which, however, the plates are sharply convex. It is remarkable among its congeners for the large size—especially length—of its radials, and the extreme convexity of the calyx; the only species at all comparable with it in the latter respect being *E. eifelensis.* It is also remarkable for the very large anal tube, composed of short and wide plates resembling those of the rays; this is well shown in both specimens, although displaced in one; the structure at its base in the other is rather peculiar, there being an irregular plate inserted at the left of what I suppose to be the posterior basal.

The basals are decidedly irregular in their development, and in figure 11*c* they seem to have no salient angles; in figure 12 it is possible that the triangular plate in the anal interradius is a basal, and the large plate to its right the first plate of the tube, thus making it still further resemble the rays. Schultze in his description says the arms have jointed pinnules at least in the upper part. This is an error; neither of the types show it, and he was probably misled by the pinnules seen in figure 11*a* which belong to an arm fragment from some other specimen, lodged in the interradius. My figures are made direct from the types—the only specimens I know.

*Types.* The complete specimen shown by figures 11*a-c* is in the Museum of Comparative Zoology at Harvard College. That of figure 12 is in the author's collection.

*Horizon and locality.* Middle Devonian, Eifel limestone; Gerolstein, Eifel Mountains, Germany.

### **Eutaxocrinus eifelensis** n. sp.

*Plate XLIX, fig. 13*

A medium-sized species. Crown elongate, broadly rounded below, widest about IIIBr, where height to width is about 2 to 1. Calyx broadly spreading 1 to 3 at IAx, where height to width is about 1 to 2; side outline convex. Crown of type specimen 30 mm. high by 15 wide; base, 4 mm. Rays with a median angular elevation extending into the arms. Arms long, relatively narrow, tapering slowly and infolding about the fourth bifurcation. Sutures arcuate.

IBB concealed by the column. BB small. RR and IBr short and wide, increasing in width upward leaving only narrow spaces for iBr, probably occupied by perisome, no iBr being seen. Brachials angular at the sides, with tendency to interlock, but without fringe or buttress. IIBr 3, short and wide; IIIBr 5 to 7 in outer ramus, 4 or 5 in inner; next division very long, branching at 15 to 20 brachials on the outer ramus, the inner perhaps remaining simple. Anal side unknown. Column large, long, tapering slightly from calyx for a short distance, with very thin columnals, which gradually increase in length without any marked point of change until they become uniformly about half as long as wide, when the column begins to enlarge again distally and the columnals become somewhat shorter; there is no alternation of columnals in length or diameter.

This Middle Devonian species is founded upon an excellent specimen from the Eifel which could not be identified with any described form, and is readily distinguished by its elongate habitus, combined with broadly spreading calyx and the angular brachial series. The stem differs materially from that of all the American species in its lack of alternating columnals; whether it does also from that of the other Eifel species we do not know, as the stem is not preserved in any of them. In the fact of enlarging distally it resembles that of *E. ithacensis.*

*Type.* Author's collection.

*Horizon and locality.* Middle Devonian, Eifel limestone or Stringocephalen-Kalk; Pelm, Eifel Mountains, Germany.

### (?) **Eutaxocrinus perplexus** n. sp.

*Plate XLVII, figs. 18a, b*

A large species. Crown elongate, widest about the third bifurcation, where height to width is 45 mm. to 25 mm.; calyx rather low and broadly spreading with side outline convex; height to width at apex of axillary IBr, 12 mm. to 23; base, 6 mm.; giving spread of base 1 to 4.

IBB low, pentagonal. BB large, and RR somewhat smaller. Post. B supporting a very large, rounded tube resembling a ray, tapering gradually, composed of very wide and short plates. Rays and their divisions divergent. Arms long, bifurcating four or five times; reducing in size by half at the first three bifurcations and tapering gradually from there on. Surface smooth. IBr wider than high, and as wide as the RR, leaving no shoulders for supporting iBr. Br of higher orders shorter than wide until near the last branches. A small quadrangular iBr in each area touches the basal in three out of the four regular interradii, and was evidently followed by perisome, as the sides of the rays above it are smooth and rounded. Column large, flush with IBB circlet, narrowing very slightly from the calyx, and composed of very thin columnals, without alternation for a distance of 20 mm.

The unique specimen upon which this species is described is abnormal in several respects, so that some of its essential characters are in doubt. The most perplexing of these is the presence of a pentagonal plate at the base of the anal tube to the left of the posterior basal, in the exact position of an obliquely located radianal. This in association with the ponderous tube so strongly suggests an affinity with *Gnorimocrinus,* that if the specimen were normal there would be no escape from referring it to that genus. The right posterior ray, however, is doubled, the primibrachs being of extraordinary width and supporting two branches, each of which has about the size and the same number of further bifurcations as the normal rays; the left posterior ray has three primibrachs instead of the normal two. Thus the posterior side of the calyx is greatly altered, and the supposed radianal may be only a sporadic occurrence. In the general character of its anal structures, with the posterior basal truncate, and anal $x$ to some extent incorporated in the calyx by sutural connection, the specimen departs from the family characters; and it must in any event be treated as a variant with characters modified by abnormal growth. In general habitus otherwise it fits as well into *Eutaxocrinus* as into any other genus.

In casting about for some possibly related form with which to compare it, one is naturally reminded of the similar huge anal tube of *E. juglandiformis,* in which the structures about the base of the tube are also out of the ordinary. In the relative size of basals and radials, and in the presence in this form of interbrachials connecting with the basals (a feature not repeated in this family until late in the Lower Carboniferous) the two species are widely different. Both depart so strongly from others of this genus that it is by no means clear that they should not be separated from it, but the imperfect and abnormal condition of the specimens in the anal parts prevents this. The fact that the specimen under consideration is derived from the same Stringocephalen-Kalk as those from the Eifel, a formation prolific in singular forms, is another reason for referring it—although with much doubt—to the present genus.

*Type.* In the author's collection.

*Horizon and locality.* Middle Devonian (Stringocephalen-Kalk); Verviers, Belgium.

### **Eutaxocrinus whiteavesi** n. sp.

*Plate XLIX, figs. 1-7*

*Taxocrinus lobatus* var. Whiteaves (not Hall), Contrib. Canadian Palaeontology, I, pt. 2, 1889, p. 94, pl. 12, fig. 1 (Adv. Sheets, 1887, p. 94, pl. 12, fig. 1).

A small species. Crown elongate, turbinate, spreading to about the level of first IVBr, where the arms infold; height to width at that level about 1.5 to 1; of calyx at top of IAx, 1 to 1.2; spread from base, 1 to 2, with nearly straight sides. Arms strong, broadly rounded below, diminishing rapidly with each bifurcation, and lying close together but not abutting; lateral margins of brachials angular or sinuous, bent sharply outward in wing-like projections fringing the arms. Sutures strongly arcuate. Surface smooth. Crown of average specimen 23 mm. high by 15 wide; base, 4 mm.

IBB low, slightly exposed beyond the column, or entirely covered. BB small, with obtuse distal angles; post. B broad, socket for anal tube slightly to the right. Anal tube not preserved intact, but evidently small, composed of elongate plates leaving considerable space chiefly at left side. RR large, twice as wide as high, without any shoulders for support of iBr; IBr of similar proportions, widening upward leaving very narrow iBr spaces which are bordered on either side by the abruptly upturned edges of these and following brachials. IIBr usually 3, rarely 4, or 2; height to width 1 to 2.5; IIIBr about the same, with 7 to 12 plates in outer divisions, and 4 or 5 in the inner; higher orders of brachials relatively narrower, with four to five bifurcations before infolding. No iBr, but spaces at primary and secondary axils evidently filled by perisome. Column large, flush with IBB; tapering slightly for a short distance; a few proximal columnals are thin and below these the alternate ossicles become longer, rounded and projecting.

The name of this species is proposed in memory of Dr. J. F. Whiteaves, the long-time paleontologist of the Geological Survey of Canada, who first figured and described a specimen of it as *Taxocrinus lobatus* of Hall, a species which is clearly distinct by reason of its 3 primibrachs, 4 or more secundibrachs, widely divergent arms and other details. In the wing-like fringe along the margins of the rays this species is distinguished from any other Taxocrinoid, the structure being entirely different from the strong lateral buttresses in forms like *Protaxocrinus interbrachiatus,* but similar to that found in *Synaptocrinus nuntius* of the Ichthyocrinidae.

There is in this species a considerable tendency to abnormal structures, several of which are illustrated on Plate XLIX. In figure 5*b* there are small intercalated plates around the posterior basal; figure 6 has but one plate below the axillary in the left posterior ray, and only the axillary in the right. Figures 7*a-e* are from a finely preserved specimen in a peculiar condition which is well shown by the diagram; it has but four rays, the right posterior being entirely wanting and represented only by the three small plates shown in figure 7*c*. Only the posterior ray is normal, the other three having but one primibrach, the axillary; and four of the basals are of unusual shapes and sizes. In figure 4 exceptionally most of the rays have 4 IIBr. The shape of the posterior basal and the position of the tube-socket are variable, but the upper margin of the plate is deeply curved toward the interior.

*Type.* The specimens considered as types, being those of figures 1, 2, 3, and 7, are in the author's collection. The original of figure 5 is in the collection presented to the University of Toronto by Sir Edmund Walker; that of figure 6 is in the American Museum of Natural History, New York; and that of figure 4 in the U. S. National Museum.

*Horizon and locality.* Middle Devonian, Hamilton group; Thedford, Ontario, Canada.

### **Eutaxocrinus gracilis** (Meek and Worthen)

*Plate XLIX, figs. 8, 8b*

*Taxocrinus gracilis* Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1865, p. 142; Geol. Surv. Illinois, III, 1868, p. 421 with text-fig., pl. 13, fig. 3.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 48.

*Rhodocrinus* (*Taxocrinus*) *gracilis,* Shumard, Trans. Acad. Sci. St. Louis, II, 1866, p. 397.

Not *Taxocrinus gracilis* Schultze, Mon. Echinodermen Eifler Kalkes, p. 37, pl. 4, figs. 3, 3*a*.

This species was described from an abnormal specimen in which the structures are so distorted that specific characters are not to be defined. It belongs to this genus, and has a habitus somewhat like that of *E. whiteavesi,* but the brachial arrangement is much more delicate, and it has small interbrachial plates. Three rays are abnormal, but the other two have 3 IIBr, and that is probably its normal number. It would thus find a place in the list just preceding *E. fletcheri.* It is probably a good species representing the genus in the western Hamilton. I give two figures of the type and only known specimen. Some other specimens probably of this genus have been found in the Hamilton of Iowa and Illinois, but not in good enough condition for description.

*Type.* University of Illinois.

*Horizon and locality.* Middle Devonian, Hamilton group; Jackson County, Illinois.

### **Eutaxocrinus ithacensis** (Williams)

*Plate L, figs. 1, 3*

*Taxocrinus ithacensis* Williams, Proc. Acad. Nat. Sci. Philadelphia, 1882, p. 28, pl. 1, fig. 10.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 3, 1886, p. 144.—Kindle, Bull. Amer. Palaeontology, II, 1896, p. 33.

A small species. Crown elongate, turbinate, narrowly expanding to IIIBr, where height to width is 1.2 to 1. Calyx narrow, with small base; side outline straight, spreading to top of IAx, 1 to 2.6; height to width, 1 to 1.2. Arms broadly rounded, tapering rapidly to small ends. Rays with smooth margins, increasing in width from RR up leaving only narrow, elongate spaces. No iBr. Surface smooth.

IBB low, like a columnal. BB small. IBr increasing in width upward. IIBr 3 or 4, the latter number predominating; two more bifurcations beyond, after which the arms infold. Column large and long, enlarging at the calyx where it is flush with the basal ring, and also toward the root; proximal columnals very thin, strongly crenulated, narrowing for about 5 mm., beyond which alternate columnals increase in length somewhat irregularly, until toward the middle of the stem they become long and convex; this continues until the column ends in an encrusting root. Dimensions of type; height of crown, 19 mm.; width, 10 mm.; base, 3 mm. Length of stem, 180 mm.; diameter at calyx, 3.2; at end of conical enlargement, 2 mm.; near root, 3 mm.

Dr. Williams in describing this species figured sections of the stem, which is substantially complete, with its root attached to a *Spirifer,* as shown by my figure 1 on Plate L—a few columnals only being missing at the fracture. The original figure is misleading and quite fails to show the slender turbinate outline of the crown, and narrow iBr spaces; compared with my figure, which is made with photographic accuracy direct from the type, it would scarcely be supposed to have been from the same specimen. The IIBr are inconstant, varying from 3 to 4, sometimes 5. The anal side is not shown, except slightly in figure 4.

This species comes from the Ithaca formation, upper Devonian. It bears considerable resemblance to *Taxocrinus communis,* from the base of the Carboniferous, from which it might not be easily distinguished but for the number of primibrachs. This and the next species occur rather plentifully in the shales about Cayuga Lake, chiefly in the form of natural moulds; but the type specimen is well preserved in its rotund condition. Apparently the attachment of the stem to other objects is a frequent condition, as Williams says it was so found in several cases.

*Types.* Museum of Cornell University, Ithaca, New York.

*Horizon and locality.* Upper Devonian, Portage group; Ithaca, New York.

### **Eutaxocrinus alpha** (Williams)

*Plate L, figs. 2, 4, 5*

When describing the preceding species Dr. Williams gave the varietal name *alpha* to a small form occurring at the same localities, but from a higher horizon. He published no figures, but later furnished me casts from the original natural moulds of the specimens which he regarded as types; these are shown by my figures 2 and 4 on Plate L, to which I add figure 5, of a specimen with a long stem having prominent elongate columnals. After the plate was printed I came into possession of a number of similar specimens of this variety having more or less of the stem preserved, all exhibiting a striking uniformity in the small size and in the stem characters. The crown is usually short, less than 5 mm. in height, with the arms limited to two visible bifurcations; and the stem is proportionally very long,—in one case 15 cm. without reaching the extremity. There are a few thin ossicles conically enlarging next to the calyx, followed by alternating ossicles, with the larger ones convex; in the median part the columnals increase in size, becoming rather uniformly elongate, barrel-shaped or doubly conical; beyond this the stem diminishes gradually to a slender thread, and the columnals become cylindrical and proportionally very much elongated. These are all thoroughly juvenile characters; but in view of the difference in horizon, and greater regularity in the size and proportions of the stem ossicles in a good series of specimens, it is advisable to recognize this form as a full species, of which figure 5 represents the typical form, rather than figures 2 and 4.

*Type.* University of Cornell; other specimens figured and studied are in the author's collection, and in the State Museum at Albany, New York.

*Horizon and locality.* Chemung group, in layers about 300 feet above those of *E. ithacensis;* Ithaca and Avoca, New York.

### **Eutaxocrinus curtus** (Williams)

*Plate L, figs. 6-9*

*Taxocrinus curtus* Williams, Proc. Acad. Nat. Sci. Philadelphia, 1882, p. 30.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 3, 1886, p. 144.—Kindle, Bull. Amer. Palaeontology, II, 1896, p. 34.

A small species. Crown short, stout, more or less rotund, widest about the upper IIBr; height to width about 1 to 1. Dimensions of mature specimen, 16 mm. high by 15 wide; base, 4.5 mm. Calyx low, broadly expanding with side outline convex; height to width 1 to 2; base broad; spread of calyx from base to IAx, 1 to 2.2. IBB hidden by column. BB very small. Rays wide and heavy, and strongly increasing in width from RR to axillary IIBr, above which the divisions become very small, in young specimens looking like mere threads. No iBr, and spaces very narrow and elongate. IIBr 3 or 4, irregularly. Column large, enlarging at the calyx with thin columnals, which alternate with longer and more convex ones farther down; mode of termination unknown.

This species is found associated with *E. ithacensis,* from which it is well distinguished by its broad and short crown and more blunt habit generally. Williams's description was made from a young specimen, on which he noted as a character that the stem does not enlarge next to the calyx. This is not the case in the adult, like the fine specimen from the New York State Museum shown by figure 8 of Plate L; and there is probably a difference among specimens in this respect due to age. The appearance of branching roots in figure 6 is misleading, caused by incidental depressions in the somewhat injured natural mould from which the impression was taken. Williams gives the horizon as Portage. There is reason to believe that the type specimen, which he did not figure but of which he sent me an impression from the original natural mould, identified as the type, was associated with variety *alpha* rather than with *ithacensis,* and therefore belongs to the Chemung. The originals of figures 8 and 9 are from Chemung beds at Avoca, Steuben County, in which *E. alpha* also occurs; the two species being thus associated at this locality probably occur in the same formation at the type locality also. The horizon of figure 7 is doubtful, and I regard figures 6, 8 and 9 as controlling for the characters of the species.

*Type.* Museum Cornell University, Ithaca, New York.

*Horizon and locality.* Upper Devonian, Chemung group; Ithaca and Avoca, New York.

### (?) **Eutaxocrinus pulcher** n. sp.

*Plate LXXV, fig. 10*

A medium-sized species, of delicate and graceful habitus. Crown elongate, very narrow, spreading but little from the base where it is flush with the top columnal. An average uncompressed specimen has the crown 40 mm. high; 10 mm. wide; base, 6 mm; calyx at top of axillary primibrach about as high as wide. iBr wanting or irregular; when present, they are usually hidden by close apposition of the arms; anal interradius extremely narrow, with post. B but slightly differentiated; anal tube not observed, but must have been very small. Arms tapering gradually to the fourth bifurcation, with relatively long brachials, and upper division series long and slender. Sutures strongly arcuate throughout. Column large, with wide proximal enlargement. Surface smooth.

IBB low, not higher than a thin columnal. BB short. RR and IBr large and of nearly equal size. IIBr 4, about half as wide as preceding plates; higher Br diminishing by about one-half at each bifurcation, but the long branches themselves taper but little.

This species is of remarkably graceful contour, with flowing lines and gentle curves. It is not as well illustrated as is desirable, because overlooked until all the plates for the Taxocrinidae were printed. The specimen figured on Plate LXXV is much flattened, and does not show the almost cylindrical form of the uncompressed crown. The anal interradius can scarcely be distinguished from the others, and upon the evidence of the specimens in the New York State Museum originally studied it was thought to be undifferentiated. Material subsequently collected by me at the type locality furnished some additional information, from which it appears that the posterior basal is somewhat larger than the others, but of similar shape; and that the anal and other interbrachial areas may be occupied by plates or perisome irregular in shape, size and position, so far as can be seen from the exterior,—largely due to the close compression of the rays, whereby the interradial structures are pushed to the inside and only incidentally exposed. There may be a small tube, invisible in the fossils as found, and the lowest plate of such a tube would be entirely separated exteriorly from the posterior basal, but supported on the shoulders of the radials—the basal not being suturally connected with plates succeeding it. The specimens upon which we have to depend occur in a micaceous sandstone, mostly in the form of natural moulds; in the few which have the skeleton preserved the preservation is unfavorable for definition of the sutures and finer structures. With the information now available, the reference to the present genus must be made with doubt. An additional figure which I had prepared will be published in the forthcoming work on the New York Devonian crinoids now in course of preparation by the New York State Museum.

*Type.* The specimen figured is in the New York State Museum at Albany; others studied are in the author's collection.

*Horizon and locality.* Upper Devonian, lower beds of the Chemung, Belmont, New York.

### (?) **Eutaxocrinus amplus** n. sp.

*Plate L, fig. 10*

An extraordinarily large species. Crown elongate and robust; the type and only known specimen is 70 mm. high by 30 mm. wide; base, 10 mm.; height to width of calyx at IAx, 1 to 1.3; spread from base, 1 to 2. Side outline convex. Arms very strong throughout, not diminishing rapidly upward; sutures broadly arcuate. iBr present. Anal structures unknown. Surface smooth.

IBB very low, not distinguishable from a columnal. BB small, in form of low pentagons. RR and IBr three times as large as BB, not materially widening upward, twice as wide as high, and of nearly equal size. IIBr 4; these and higher Br in each division of about the same size, wider than high, and each about two-thirds as wide as those of the preceding division. Branching above IIBr somewhat irregular, with 5 to 10 plates in outer ramus of IIIBr and 4 to 7 in the inner, and longer intervals above; one ray probably injured and recuperated. Arms extending beyond fourth bifurcation, and infolding at about that level. iBr few, narrow and elongate, in 2 or 3 ranges; a small iIIBr present. Column large, tapering rapidly from the calyx at first and then gradually until becoming cylindrical, with slightly alternating columnals of even diameter.

This species is proposed upon a single specimen from the New York Chemung, being an impression from a natural mould in the collection of the late Professor James Hall now in the University of Chicago. In its peculiarly large and robust habit it is unlike any other of this genus, and looks more like a specimen of *Onychocrinus ramulosus*. This resemblance is heightened by the presence of two or three irregular ramule-like arm-branches, but in general structure the arms are in nowise like those of that genus. Lack of knowledge of the anal structures makes the generic position of the species uncertain.

*Type*. University of Chicago.

*Horizon and locality*. Upper Devonian, upper beds of the Chemung group; Binghamton, New York.

### **Eutaxocrinus fletcheri** (Worthen)

*Plate L, figs. 11-19*

*Taxocrinus fletcheri* Worthen, Bull. I, Illinois St. Mus., 1882, p. 31; Geol. Surv. Illinois, VII, 1883, p. 308, pl. 30, fig. 2.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 3, 1886, p. 144; Geol. Surv. Illinois, VIII, 1890, p. 197, pl. 15, figs. 6, 9.

A medium-sized species. Crown rather short, robust, turbinate almost to the top; greatest width in adult specimens about the fourth or fifth bifurcation, where height to width is about 1.4 to 1. Calyx proportionally slender with a broad base, side outline straight; height to width at IAx, 1 to 1.4; spread from base, 1 to 1.4. Arms robust below, branching with short divisions five times before infolding in adult specimens, three times or less in young; diminishing rapidly with each bifurcation to slender finials; sutures arcuate. Anal tube small, bordered by finely plated perisome and merging into it distally, composed of elongate plates; iBr present. Column very thick, flush with base and enlarged next to calyx, narrowing in proportion of 1.4 to 1 in about 15 mm., with very thin columnals in the conical part; below that alternate columnals becoming longer and rounder; it decreases in diameter distally, and apparently terminates in a narrow end without root. Dimensions: crown in maximum specimen, height, 34 mm.; width, 20 mm.; base, 9 mm. Average of 4 adults: height, 29 mm.; width, 19 mm.; base, 9 mm. Of a young specimen: height, 12 mm.; width, 9 mm., base, 4 mm. Of column in a medium specimen: diameter at calyx, 8.5 mm.; at end of conical enlargement, 6 mm.; in middle, 5 mm.; near distal end, 2.7 mm.; length of 23 ossicles in conical part, 15 mm. (=.6 mm. each); total length to near the probable termination, 16 cm.

IBB low, resembling a thin columnal. BB fairly large, short and broad with obtuse angles. RR and IBr of nearly the same size and form, more than twice as wide as high. IIBr 3, sometimes 2, shorter than and nearly as wide as the IBr. IIIBr much smaller, 4 in outer and 3 in inner ramus; followed by rapidly diminishing branches with 6, 7, 8 brachials in the outer ramus to the VIIBr, which has 8 in one specimen. iBr spaces very narrow, with 1 to 3 small plates between the rays, and occasionally similar elongate ones in the first axil.

This species and the next are the only Carboniferous representatives of the genus, and mark its end in the earliest formation of that epoch. The description is made from a fine series of well-preserved specimens, eight of them entirely free from the matrix, and three with long stems on slabs. The characters are remarkably constant throughout this material, notably the shorter intervals between the bifurcations than in other species; thus in the 40 rays of the eight free specimens not one has over 3 IIBr, and few have more than 4 or 5 outer and 3 inner in the next division; quite a number of rami have only two IIBr, and occasionally there is but one. The whole tendency is to shortness of the crown, notwithstanding the large number of bifurcations. The stem apparently tapers to a point without any such enlargement as in *E. ithacensis,* and probably without branches; it is preserved almost to the end in a specimen on a large slab, from which the terminal restoration in figure 12 was made. The socket on the posterior basal for the reception of the anal tube is more asymmetric than the figures show. In specimens as usually found, the rays are so closely appressed that the projection of the basal at the left upper corner is hidden from view, so that the tube appears as if median; and in some cases probably is so. In figure 15, Plate L, the asymmetry is indicated, but further preparation of this and other specimens shows it to be much more pronounced,—the structure in this respect being that of the typical Taxocrinoid.

*Types.* Worthen's original is in the University of Illinois; the others figured and studied herein are in the author's collection.

*Horizon and locality.* Lower Carboniferous, Kinderhook group; Le Grand, Iowa.

### **Eutaxocrinus montanensis** n. sp.

*Plate L, fig. 20*

Among some collections in the National Museum from the Madison limestone in Montana is a single specimen rather closely related to the last species, and yet of a habitus fairly distinct from it. The horizon is nearly equivalent to the Iowa Kinderhook of Le Grand, faunally and lithologically. The rock is a very similar buff limestone, but thin and irregularly bedded; and it has a crinoidal fauna with an extraordinarily similar facies, yet with scarcely a species that can be called absolutely identical; the differences are those due to migrational changes, modifying the types without extinction of the fauna. The specimen for which I have proposed the above species is an example of this. Upon the diagnostic character of having few iBr, 3 IIBr, and a turbinate contour, it must stand close to *E. fletcheri,* yet it is clearly of a more elongate type, with Br relatively much longer and narrower, iBr spaces larger, and much larger IBB. It is also a larger species, the calyx to the top of IAx being higher by half than that of the largest specimens of *E. fletcheri.* The specimen is only partially exposed, and somewhat distorted, so that a more detailed description is not practicable; the form of post. B as seen in the figure is misleading, the left upper part being pushed under the adjoining radial. The socket for the anal tube was about median.

*Type.* U. S. National Museum.

*Horizon and locality.* Base of the Lower Carboniferous, Madison limestone (=Kinderhook group); Spring Canyon, Montana.

## **TAXOCRINUS** Phillips

*Plates LI-LX; text-figs. 28a, c; 32-34*

*Taxocrinus* Phillips in Morris, Cat. British Fossils, 1st Ed., 1843, p. 59 (2d Ed., 1854, p. 90).—M'Coy, Carb. Fossils Ireland, 1844, p. 178; British Pal. Fossils, 1854, p. 53.—Bronn, Index Palaeontologicus, I, 1848, p. 1217; Lethaea Geognostica, I, 1851, p. 22; Klassen u. Ord. Thier-Reichs, 1860, p. 231.—D'Orbigny, Cours Elem. Pal. et Geol. Strat., II, 1851, p. 145.—Quenstedt, Handbuch Petrefaktenkunde, 1852, p. 617; Petrefaktenkunde Deutschlands, IV, 1876, p. 503.—Muller, Monatsber. Akad. Wiss. Berlin, June, 1856, p. 353; Abhandl., 1857, p. 244; Monatsber. Akad. Wiss. Berlin, 1858, p. 185.—Sandberger and Sandberger, Verstein. Rhein. Schicht. Nassau, etc., 1850-56, p. 392.—Pictet, Traité Paléontologie, IV, 1857, p. 327.—Hall, Geol. Surv. Iowa, I, pt. 2, 1858, p. 482.—Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, XVII, 1865, p. 138; Geol. Surv. Illinois, II, 1866, pp. 268-272.—Shumard, Trans. Acad. Sci. St. Louis, II, 1866, p. 397.—Schultze, Mon. Echinodermen Eifler Kalkes, 1867, p. 33, with text-fig.—Beyrich, Monatsber. Akad. Wiss. Berlin, 1871, p. 43 (Transl. in Ann. and Mag. Nat. Hist., (4) VII, p. 401).—Salter, Cat. Cambrian and Silurian Fossils, 1873, p. 125.—Meek, Amer. Jour. Sci., (3) VII, 1874, p. 191.—Wachsmuth, Amer. Jour. Sci., XIV, 1877, p. 184.—Wachsmuth and Springer, Proc. Acad. Nat. Sci. Philadelphia, 1878, p. 252; Revision Palaeocrinoidea, pt. 1, 1879, p. 43; pt. 3, 1886, p. 144; Proc. Acad. Nat. Sci. Philadelphia, 1888, p. 344; 1890, p. 353.—Von Zittel, Handbuch Palaeontologie, I, 1879, p. 353; Grundzüge d. Palaeontologie, 1895, p. 138.—Carpenter, Philos. Trans. Roy. Soc. London, CLXXIV, 1884, p. 930.—Miller, N. A. Geol. and Palaeontology, 1889, p. 285.—Zittel-Eastman, Textbook Palaeontology, 1896, p. 163 (2d Ed., 1913, p. 206).—Jaekel, Zeitschr. d. deutsch. geol. Gesell., for 1897 [1898], p. 46.—Bather, Nat. Science, XII, 1898, p. 341; Treatise on Zoology (Lankester), pt. 3, 1900, p. 189; Ann. and Mag. Nat. Hist. (8), XII, 1913, p. 390.—Springer, Amer. Geologist, XXX, 1902, pp. 90, 95; Jour. Geology, XIV, 1906, pp. 467-523.

*Isocrinites* (*Isocrinus*) Phillips, Palaeozoic Fossils Cornwall, 1841, pp. 29, 30 (not von Meyer in Agassiz 1835).—Austin and Austin, Ann. and Mag. Nat. Hist., X, 1842, p. 108.

*Cladocrinites* Austin and Austin, Ann. and Mag. Nat. Hist., XI, 1843, p. 197 (not *Chladocrinus* Agassiz, 1836).

*Euryalecrinus* Austin and Austin, Mon. Rec. and Foss. Crinoidea, 1846 [1843-49], p. 66.

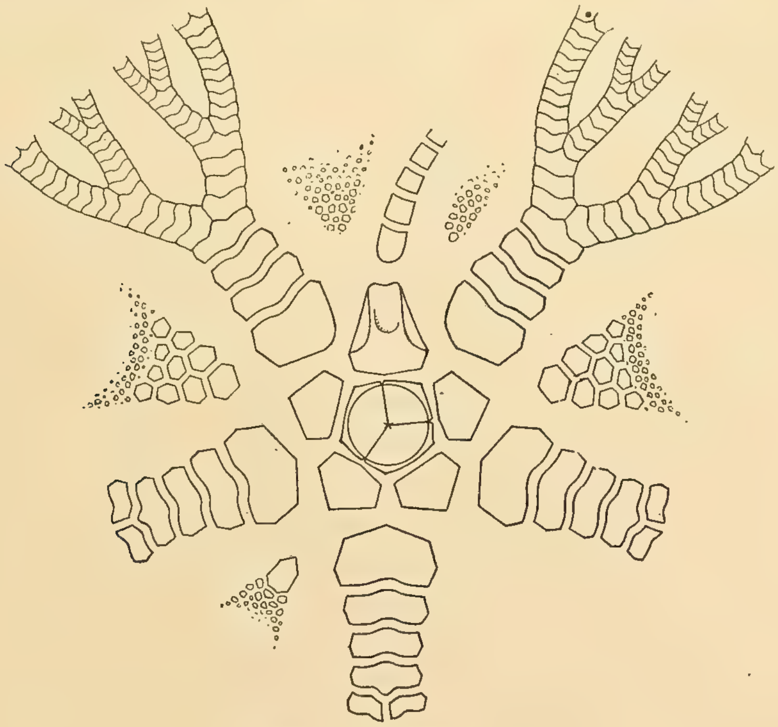

FIG. 49. *Taxocrinus*

Taxocrinidae with rays not abutting over interbrachial areas. Infrabasals low, forming but a small part of the calyx wall; sometimes entirely concealed by the column. Posterior basal elongate. Radianal, if present, only in upper oblique position. Interbrachials variable, usually present in lower part of area; frequently numerous, with distal margin crescentic, rising toward the rays; sometimes wanting. Primibrachs three. Arms dichotomous, divergent. Column usually enlarging proximally. Tegmen composed of pliant skin with calcareous spicules imbedded, traversed by calcified ambulacra passing between parted orals to an open mouth. Anal opening excentric, at the end of a tube formed by extension of the ventral perisome and supported at the posterior side by a vertical series of anal plates.

*Genotype. Cyathocrinus ? macrodactylus* Phillips.

*Distribution.* Middle Devonian to close of Lower Carboniferous; Great Britain, Belgium, and the United States.

*Taxocrinus* is a perfectly typical genus of its family. The structure of the posterior side, with its anal tube originating on the posterior basal sometimes far down upon that plate, and connected with the rays on one or both sides by perisome only, is in complete contrast with that of *Forbesiocrinus,* with which it has been most frequently confounded. The details of this structure have been fully given in the discussion under that genus, and it is unnecessary to repeat them here. Something further may be added, however, as to the so-called anal tube.

Although the vertical series of plates in the posterior interradius in this and allied genera has been sometimes called an " anal tube," there has been a tendency among authors to use the term with qualification and caution, so as to avoid the meaning of an actual tube, it being generally assumed in later years that this structure does not represent such an organ. My own investigations, with material and preparations not accessible heretofore, have shown that the long familiar term expresses the facts better than any other, and may be properly used in description without circumlocution.

While the plates which constitute the vertical series as we see it in a dorsal view are not themselves hollow, yet they form the support for a fold in the perisome which is in every way analogous to the passage for the hind gut. The organ thus formed is a jointed structure, and therefore flexible notwithstanding the solidity of its plates; composed on the dorsal side of a series of heavy, rounded, elongate plates, which are articulated with one another. In the best developed forms of *Taxocrinus,* as well as in the closely allied *Onychocrinus,* where the tube originates half way down on the outside of the posterior basal, the lower plates to the extent of one or two are perfectly solid, and rest within a socket and groove in the posterior basal. Above this the plates become ventrally crescentic, and the perisome is attached to their lateral edges by a distinct line of depression cut out for its accommodation (Pl. LXVII, figs. 4, 6). A portion of the pliant tegmen is gradually lifted up between the posterior oral and the anal series until it protrudes in the form of an inverted funnel-shaped passage; it thus comes to form the ventral side of an elevated tube for the exit of the rectum and the discharge of excrement away from the oral center. There are in some species from 7 to 10 of these heavy, jointed plates, and in *Onychocrinus* from 10 to 13—the terminal one being rounded, and appearing as if attached to the perisome (Pl. LXVII, fig..3*b*).

As found in the fossil state in the latter genus, with the tegmen invariably compressed, distorted, or collapsed and sunk down into the dorsal cup, the tube is often curved first to the left against the radial of that side and then to the right, the upper portion lying close behind the edge of the posterior basal. Pressure of the tube against this radial plate, coupled perhaps with the friction due to the opening and closing of the rays and the up and down movement of the tegmen, sometimes produced a broad vertical groove on the margin of the left posterior radial, which is a further striking evidence of the great mobility of the *Onychocrinus* calyx (text-fig. 8). In most of the species the socket for the tube lies well to the right side of the basal, and in some, such as *T. lobatus, T. intermedius, T. ungula* and *T. giddingei,* the first plate is larger than those following it, and occupies an angular space between the upper shoulders of the posterior basal and the right posterior radial; in these cases the plate is believed to represent the radianal, moved upward concurrently with the elongation of the posterior basal to an upper oblique position.

Our knowledge of the tegminal part of this structure in *Taxocrinus* is mainly derived from the famous specimen of *T. intermedius* discovered by Wachsmuth and Springer in 1888 (Proc. Acad. Nat. Sci. Phila., p. 344), which first gave a clue to the true ventral structure of the Flexibilia. But the posterior aspect of the tube and its connecting perisome is so perfectly shown in the specimens of *Taxocrinus lobatus, T. ramulosus* and *T. whitfieldi,* that we may consider it to be substantially the same as in *Onychocrinus,* where we have it somewhat better preserved. The actual opening has not been seen in any specimen, and we should scarcely expect to find it, being an aperture through the delicate perisome which is always more or less folded upon itself and flattened. Otherwise the whole structure is completely and beautifully shown by my specimens of *Taxocrinus* and *Onychocrinus,* especially a series of *O. ulrichi* specially prepared for the purpose (Pl. LXVII, figs. 2-6). The form of the posterior oral is different in the two genera, and apparently the tube was longest in *Onychocrinus.*

The structure of the entire tegmen in *Taxocrinus* is perfectly shown in the specimen of *T. intermedius* above mentioned (Pl. LIII, figs. 1*a, b*). The orals are well rounded and separated, and do not form such a distinct pyramid as part of them do in *Onychocrinus.* The ambulacra are small and delicate, with covering plates transversely elongate—that is, short and wide. This structure has been confirmed in a specimen of *T. shumardianus* (Pl. LIX, fig. 14*b*).

Along with the above-mentioned characteristic anal structure go two other characters also fully discussed under *Forbesiocrinus,* which must be remembered in trying to determine to which of the two genera a specimen should be referred, viz.: (1) that in *Taxocrinus* one or both margins of the brachials next to the anal interradius are smooth, rounded, without markings or any specialized area for sutural attachment; and (2) that the interbrachials are rarely suturally united to the rays higher than the last secundibrach, and that in the later developed *Taxocrini* they slope away from the rays so as to form a concave distal margin, instead of a lanceolate area wedged in between the rays as in the species of *Forbesiocrinus* of corresponding horizon. In practice these facts are important, and often serve to settle the identification in cases where the anal structure is invisible, or deceptively distorted by pressure. The last feature is not so well marked in the Devonian and earlier Carboniferous species, with their narrow interbrachial areas, while the contemporary *Forbesiocrinus* of the *nobilis* type has the crescentic margin of the interbrachials though somewhat different in detail. But in the species of the Upper Burlington, Keokuk, St. Louis and Kaskaskia, where there is greatest occasion for comparison with *Forbesiocrinus,* the crescentic interbrachial margin is very conspicuous, while in the species of *Forbesiocrinus* from some of the same formations the areas are invariably filled to an apex between the rays.

In the matter of interbrachials the genus underwent a considerable progressive modification. Certain Devonian species, among the earliest occurrences of the genus, have no regular interbrachials, and apparently no place for any. Others, also in the Devonian but including species as late as the Lower Burlington, have a few interbrachials confined to the lower part of the areas. A third set of species, beginning in the Kinderhook and including all species from the Upper Burlington to the expiration of the genus in the Kaskaskia, have the interbrachials strongly developed, rising well up along the rays and forming a concave distal margin as already explained. The boundaries between the three sections are not sharply defined, yet the general course of development is evident; but in this respect it never, in the Lower Carboniferous, went beyond the stage in which *Forbesiocrinus* began in the early part of that period. While, therefore, there are in the later Keokuk and Warsaw species of *Taxocrinus* with a profuse growth of interbrachials which have a superficial resemblance to *Forbesiocrinus,* the manner in which these plates are disposed along the distal margin can be relied upon to distinguish them. This is the case with species in which the structure of the anal series is intermediate by reason of a strong growth of plates larger than the ordinary perisomic plates at either side of the anal series—such as *T. giddingei* (Pl. LIX, figs. 3, 5).

There are also Taxocrinoid forms having some anal plates attached to the right posterior ray. These are often perplexing, and cause doubt to which family they should be referred. If we could see the entire posterior basal in direct view we should probably find in those cases also an approach to sutural connection at the distal face. They are intermediate forms, in which their position must be determined by a slight preponderance of characters.

It will be seen from the foregoing statements that while there was a progressive development of the interbrachial system both in *Taxocrinus* and *Forbesiocrinus,* these changes were not synchronous. *Taxocrinus* reached its acme in this respect in the earliest Lower Carboniferous, at about the same time that *Forbesiocrinus* first appeared in a very similar stage of interbrachial development, and thereafter in the latter genus the growth of these parts increased until the areas were completely filled. Thus *Taxocrinus intermedius* of the Kinderhook is in substantially the same stage as *Forbesiocrinus nobilis* of the approximately equivalent Mountain limestone, and they can only be distinguished generically by the anal side; while all later *Forbesiocrini* can be readily distinguished from the later *Taxocrini* by the interbrachials as well as by the other characters.

In *Onychocrinus* the order of development of interbrachials was reversed, being profuse in the early stages followed by marked diminution toward the end. That genus is fundamentally a *Taxocrinus* with heterotomous arms—the same modification that is seen between the Inadunate forms *Cyathocrinus* and *Barycrinus.*

The stem of *Taxocrinus* was of considerable length in the later Carboniferous species, being much longer in *T. colletti* from the Keokuk than in *T. communis* from the Waverly. Unfortunately the complete stems are so rarely preserved that no satisfactory comparison can be made between the species generally.

As the genus was formerly regarded by authors, *Taxocrinus* extended as far back as the Ordovician, and included a variety of types the characters of which were not understood; later investigations have shown the necessity of distributing them in the genera *Protaxocrinus, Meristocrinus, Gnorimocrinus* and *Eutaxocrinus.* This leaves the parent genus a compact, homogeneous group, beginning in the Middle Devonian, distinguished from all the others by the absence of a radianal and the presence of three primibrachs. Only in the latter character is there found a slight instability during the transition epoch of the Devonian, when the evolution from two to three primibrachs as a constant character took place. The genus culminated in the Lower Carboniferous, where it is represented by a number of vigorous species; and it continued to the end of that period.

The nomenclatorial history of *Taxocrinus* is long, and is involved in a singular maze of confusion. Although the most widely accepted genus of the Flexibilia, and one to which more species have been referred by both European and American authors than to any other, it is rather curious that its name and definition can scarcely be traced to a definite and authoritative origin, but must be deduced from somewhat complicated and contradictory literature. Both, however, can in my opinion be placed upon a sound basis.

The type, in its generalized facies, which is now taken to represent the whole Flexibilia group, was clearly recognized by that keen observer, John Phillips, in 1841, when describing his *Cyathocrinus* ? *macrodactylus* (Palaeozoic Fossils of Cornwall, etc., p. 29). From the context it appears clear that it was the study of this species which suggested the idea of a new generic group, which "unlike other *Cyathocrinites* and *Poteriocrinites* might be characterized by having the scapular, costal, and cuneiform arm base *in one row and of one breadth*";—a feature which is one of the salient characters of the Flexibilia generally. Immediately following the description of the above-mentioned species he said: "On comparing this form with *Poteriocrinus* (?) *egertoni* and *Poteriocrinus nobilis* [previously described by him] and *Cyathocrinus tuberculatus* [of Miller], it appears that they are congeneric." For this group he proposed the name *Isocrinites,* indicating the specific characters as "depending on the number of plates in the costal, brachial, and digital series"; and he listed the species as follows:

*Isocrinus egertoni,* to have seven costals.
 *tuberculatus,* three costals and three brachials.
 *macrodactylus,* four costals, five brachials, and six, ten, fifteen digitals.
 *nobilis,* four costals, four or five brachials, and four, etc., digitals.

While proposing the name *"Isocrinites,"* it is interesting to see that on the same page he listed the species under *"Isocrinus."*

It is important to note that the "costals" of Phillips included both radials and primibrachs of present terminology, for on p. 29, under *C. macrodactylus,* he said: "The pentagonal supra-columnar joint is surmounted by five plates (pelvis of Miller), alternately with which, and above them, are five rows of broad costal and scapular plates, four in each, the last being cuneiform";—*i. e.,* the fourth plate is the axillary; hence there is a radial and three primibrachs.

Phillips's choice of the name *Isocrinus* was unfortunate, it being preoccupied by Von Meyer in Agassiz in 1835;[1] and the Austins in proposing as a substitute for it in 1843 Agassiz's name *Cladocrinites* [*Chladocrinus*] fared no better. Having discovered that this name was preëmpted, they made another effort when preparing their Monograph on Recent and Fossil Crinoids, which they began to publish in parts in 1843; and on p. 66 of that work (in a part which was not published until 1846) we find the name *Euryalecrinus* as a new genus in which Miller's *C. tuberculatus* has been included. This was evidently left in the text by oversight, as on a previous page (61) they use the name *Taxocrinus* for *longidactylus,* one of the species which had been ranged under *Cladocrinites* in 1843—thus showing that they had already learned of Phillips's new name as promulgated by Morris.

In 1843 Morris, in the first edition of his Catalogue of British Fossils, p. 59, published the name *Taxocrinus* credited to Phillips, listing the species under it as follows:

*Taxocrinus egertoni.*
 *macrodactylus.*
 *nobilis.*
 *tuberculatus.*

There is no evidence of any publication or definition of the genus under this name by Phillips, and the work of Morris must be taken as fixing its date and standing. No definition was given there, but from the names of the species it is sufficiently clear that the genus was intended for the group previously defined by Phillips under *Isocrinus.* No type species was indicated by Morris, and no guide to this is furnished by the order in which the species are mentioned, which is purely alphabetical. Neither did Phillips designate any type among his original list of species under *Isocrinus.* It has been assumed by some authors that *I. egertoni,* because standing first in that list, should be taken as the type of the genus. But without any indication by the author of such purpose in the arrangement this fact is by no means so important as the fact that the species which Phillips personally studied at the time he proposed the genus, and the consideration of which evidently induced the recognition of the generic type, was *I. macrodactylus.*

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[1] *Isocrinus,* H. de Meyer (encore inédit), Mem. Soc. Nat. Neuchatel. I, 1835, p. 195. *Isocrinus,* H. von Meyer (Letter to Bronn), Neues Jahrb. Min. 1836, p. 57; Mus. Senkenbergianum, 1837, p. 251.

The first author to treat of *Taxocrinus* after its publication by Morris was M'Coy, who in 1844 (Carb. Foss. Ireland, p. 178) gave a generic diagnosis, and out of all the species named by Phillips selected *T. macrodactylus* for a full specific description, following it by a new species of his own. This was accepted as conclusive by that careful and judicious paleontologist F. B. Meek, who in connection with Worthen in 1866 (Geol. Surv. Illinois, vol. 2, p. 271) said:

> "As M'Coy, who first followed Phillips in the use of the generic name *Taxocrinus* (1844), evidently viewed *T. macrodactylus* as the typical form of the genus, it would, according to the most generally accepted rules of naturalists, become the type of the genus for all time to come."

This statement was made in the course of an elaborate discussion of the relations of the genera *Taxocrinus* and *Forbesiocrinus,* and it is the first formal designation of the type species of *Taxocrinus* to be found in the literature. Therefore, under Article 30 of the revised International Code as interpreted by the leading authorities, *T. macrodactylus* becomes the type by subsequent designation.

Of the other species assigned to the genus by Phillips, *T. tuberculatus* has been removed to constitute the type of *Temnocrinus; T. egertoni* may belong to *Onychocrinus,* but is not well understood and the type specimen cannot be found. This leaves only *T. nobilis,* which goes readily with *T. macrodactylus* as a good representative of the genus as now restricted.

Pacht in 1852 (*Dimerocrinites oligoptilus,* p. 7), in ignorance of Phillips's proposal of *Taxocrinus,* and mistaking entirely the nature of his genus *Dimerocrinites,* referred the species *nobilis* and *tuberculatus* to the latter.

Roemer in 1851, and subsequently in Bronn's Lethaea Geognostica (1852-54), rejected *Taxocrinus,* and referred all its species to *Cyathocrinus*—a course which has not been followed by any other author.

De Koninck and Le Hon in proposing their genus *Forbesiocrinus* in 1854, undertook to limit *Taxocrinus* to species without any interradials (interbrachials); but their proposal was rejected by subsequent authors, such as Schultze, Meek and Worthen, and Wachsmuth and Springer, in the course of extended discussions. On the other hand the presence of interradials as a generic character was expressly stated in the same year by M'Coy as separating the genus from *Ichthyocrinus.*

The genus has been recognized in the sense of Phillips by authors generally since Roemer's time, with a tendency sometimes to enlarge, and again to restrict, its limits. Schultze (1866) found scarcely enough ground to distinguish *Forbesiocrinus* from it; Meek and Worthen (1866) proposed to include that genus, and even *Onychocrinus,* as mere sections under *Taxocrinus;* Beyrich (1871) expressed the opinion that these genera "can only be retained if *Taxocrinus* be limited to those species in which the first division of the radii takes place on the third joint, while four primary radial segments are characteristic of *Forbesiocrinus.*" He meant the "third joint" including the radial, *i. e.* $IBr_2$, and his plan cannot stand because it thus necessarily excludes the type species, *T. macrodactylus.* Wachsmuth and Springer in 1878 went beyond all others in the direction of consolidation, concluding that both *Taxocrinus* and *Forbesiocrinus* should be considered at the most as only subgenera under *Ichthyocrinus.* A better understanding of the whole group resulting from later investigations modified this opinion, and in the Revision of the Palaeocrinoidea, part 1 (1879), we pointed out the fundamental characters in the structure of the anal interradius on which the genus is separated from all those with which it has been confused, save only *Onychocrinus,* and in which it becomes the representative of a well-defined and larger family group. This conclusion regarding the genus has been accepted by subsequent authors without dissent.[1]

No notice was taken of any anal structures in any of the earlier diagnoses or descriptions of this genus, nor, as was the case in many other genera, of the fact that it has a dicyclic base. Johannes Müller in 1858 (Monatsber. Berlin Akad., p. 185), was the first to demonstrate the presence of three small plates below those which were before supposed to be the lowest plates of the calyx; and Schultze in 1867 (Echinodermen Eifler Kalkes, p. 32) called these small plates "cryptobasalia" because they are usually hidden by the column.

The Austins and M'Coy added to Phillips's original list several new species from the English and Irish Carboniferous; Roemer, Müller, and Schultze four or five more from the Devonian of the Rhineland; while still others were added by the American paleontologists from the Devonian and Carboniferous of this country. In the meantime Angelin, in 1878, described under this genus several more new species from the Silurian of Gotland; and two species described by Billings as *Lecanocrinus,* from the Ordovician of Canada, were referred to it by Wachsmuth and Springer. Thus by the year 1900 the apparent range of the genus had been extended so as to include forms from the Lower Ordovician (Trenton) to the highest Lower Carboniferous (Kaskaskia); and more than fifty species had been referred to it.

Angelin's *Taxocrini* were separated by Wachsmuth and Springer in 1879 under their new genus *Gnorimocrinus,* upon rather unsatisfactory characters as then stated; the genus is now better defined and may be retained as valid, but not all of Angelin's species fall under it. There still remained a great aggregation of species which was not only unwieldy in itself by reason of its number, but objectionable because upon geological grounds it seemed highly desirable to find some basis for separating the Ordovician species from those of the Carboniferous. Considering the progressive modifications of structure that were known to have taken place among the Inadunata, and the fact that closely parallel changes had occurred in the Ichthyocrinidae, it seemed to the last degree improbable that such a form as *Taxocrinus* should persist from the Ordovician to the latest Lower Carboniferous without any modification of more than specific importance. Satisfactory grounds for separation were finally found by me in the anal and brachial structures, forming the basis of several homogeneous and practicable generic groups.

*T. tuberculatus,* one of the species originally included by Phillips, was removed to become the type of *Temnocrinus,* and falls into a different family. The Ordovician and all but one of the remaining Silurian species were separated under *Protaxocrinus* and *Meristocrinus.* All of these older forms are clearly marked off by the presence of a radianal in some distinctive lower position.

The subdivision of the Devonian and Carboniferous *Taxocrini,* in which the radianal has been shifted upward or eliminated, does not follow sharp stratigraphic lines, being based upon a modification in brachials which began in the Devonian and was not concluded until the early Carboniferous. The type represented by the parent genus culminated in the latter part of the Lower Carboniferous, where it was widely distributed and characterized by several well-marked and abundant species. The form thus persisting is that of the Devonian genotype, *T. macrodactylus,* having " four costals," or in our terminology a radial and three primibrachs; and it therefore necessarily holds the name *Taxocrinus.* The other form, retaining the Silurian characteristic of a radial and two primibrachs only to the earlier part of the Lower Carboniferous, has been removed to form the genus *Eutaxocrinus.* The modification from two to three primibrachs thus took place in the Devonian; and among the species of that age there is observed a tendency to variation, and some lack of constancy in this character. By the time of the Burlington limestone the three-primibrach form, or *Taxocrinus,* had become thoroughly established, and continued on through the St. Louis and Kaskaskia to the extinction of the group; whereas that with the two primibrachs, or *Eutaxocrinus,* had completely disappeared—the latest known species occurring in the lowest member of the Lower Carboniferous, the Kinderhook.

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[1] The diagnosis of *Taxocrinus* quoted in Revision of the Palaeocrinoidea, pt. 1, p. 43, as being from Phillips, must be taken as Wachsmuth's interpretation of the several definitions, chiefly those of M'Coy in 1844 and 1854, which by some *lapsus pennae* was placed within quotation marks. It is couched in modern terminology, not employed at those dates. It is also incorrect in stating that the "arms divide upon the third radial,"—as Phillips in his definition of *Isocrinus* expressly included species with more than "three costals," and the type species, *T. macrodactylus,* was said to have, and actually has, four.

The species of *Taxocrinus* arrange themselves progressively into three not very sharply defined groups, which nevertheless in a general way coincide with the development of the especially strong characters of the genus, and its subsequent decadence; these are based upon the condition of the interbrachial system, as follows: (1) iBr wanting, Devonian; (2) iBr few, with areas narrow, chiefly filled with perisome, Devonian to early part of Lower Carboniferous; (3) iBr well developed, with wide areas and numerous strong plates, Lower Carboniferous.

The criteria for the closer discrimination of species are not in all cases as definite as could be wished. This is especially the case with the Devonian species, in regard to which we are embarrassed by scarcity of material, specimens for the most part being extremely rare and in the English species very poorly preserved. We have to rely to a large extent upon characters which cannot be very accurately defined and do not lend themselves advantageously to analytical statement; such for instance as comparative size, the tapering of the arms, etc. In the Lower Carboniferous, from which we have in most cases an abundance of well-preserved specimens, the species are usually well-marked, especially toward the close of that epoch. Nothing could be sharper and more satisfactory than the characters of such notable species as *T. colletti* and *T. ungula,* or the distinction between the last three or four small species with which the genus ended. The number of secundibrachs is not a reliable character throughout, being subject to considerable variation in the Devonian species. In a general way it may be said that the elongate species have 4 or more, and the short-crowned species less than 4. In the later Lower Carboniferous the number of these plates becomes more constant, with a tendency to shortening of the intervals in the ray divisions, until in the last surviving species the number is reduced to 2 IIBr almost without exception, and to 2 or 3 IIIBr—a condition closely paralleled in the latest species of *Onychocrinus* of the same formation.

Five species are recognized in the Devonian, and sixteen in the Lower Carboniferous. The genus began feebly in the middle part of the Devonian, struggling along with a few species while the antecedent *Eutaxocrinus* was running its course to extinction in the beginning of the Carboniferous; it then reached its acme in America during the first half of the Lower Carboniferous with 3 species in the Kinderhook-Waverly; 4 in the Burlington (including Knobstone); and 3 in the Keokuk; it then entered upon its decline, finishing with one small species each in the Warsaw, St. Louis, and two in the Kaskaskia.

The relation of the species may be shown by the following analysis, beginning with the earliest, and proceeding with a more or less interrupted progression to the end at the close of the Lower Carboniferous:

### THE SPECIES OF TAXOCRINUS

- I. iBr none.
  - Crown elongate, calyx narrow.
    - Arms tapering rapidly.
      - IIBr 5 or more.
        - Stem enlarging at calyx.................................*T. macrodactylus.*
        - Stem not enlarging at calyx.................................*T. stultus.*
- II. iBr few.
  - iBr areas narrow.
    - Crown elongate.
      - Arms tapering slowly.
        - Calyx narrow, turbinate; base small.
          - IIBr 4. IIIBr inner division longest..................*T. interscapularis.*
          - IIBr 5. IIIBr outer division longest..........................*T. telleri.*
    - Crown short and broad.
      - Arms tapering rapidly.
        - IIBr 4 or 5.
        - Calyx narrow, slightly curved.
          - Stem not enlarging at calyx..............................*T. communis.*
      - Arms heavy and tapering slowly.
        - Calyx broad and massive, subturbinate.
          - Stem enlarging next to calyx.
            - IBB within ring of BB.................................*T. nobilis.*
        - Calyx more rounded.
            - IBB visible outside of column............................*T. belgicus.*
  - iBr areas wide, filled with perisome.
    - Crown elongate.
        - Calyx spreading.
          - Arms heavy, tapering slowly.
            - Arms with nodes on axillaries.
              - Anal tube very conspicuous............................*T. lobatus.*
              - Anal tube very small.................................*T. kelloggi.*
            - Arms marked with wrinkles............................*T. ornatus.*
            - Arms marked with pustules..........................*T. pustulosus.*
        - Calyx narrow.
            - Arms tapering rapidly, surface smooth......................*T. juvenis.*
- III. iBr well-developed.
  - iBr areas wide, numerous strong plates in lower part.
    - Species attaining large size.
      - Crown short and spreading.
        - IIBr 3.
          - Calyx evenly rounded, rays not prominent.
            - Arms tapering rapidly from IIBr..........................*T. intermedius.*
          - Calyx pentagonal, rays prominent.
            - Arms tapering gradually throughout....................*T. ramulosus.*
            - Arms sharply diminishing above IIIBr and spreading like claws.........................................*T. ungula.*
      - Crown elongate.
        - Arms long, regularly tapering.
          - Stem enlargement suddenly contracting.
            - IIBr 3 or 4.........................................*T. colletti.*
          - Stem enlargement gradually diminishing from calyx.
            - IIBr 4.............................................*T. praestans.*

- Species small and short.
  - Crown wide and spreading.
    - IIBr 3.
      - iBr not touching BB; anal series bordered by strong plates....*T. giddingei.*
      - iBr touching BB; anal series bordered by weak perisome;
        - IIIBr 3 at inner side of ramus.
          - Crown rather longer than wide; rays low and broadly rounded ............................*T. shumardianus.*
          - Crown smaller than in all other species; wider than long; rays rather narrowly elevated..............*T. huntsvillae.*
    - IIBr 2.
      - iBr very strong, sometimes touching BB; IIIBr 2 or 3........*T. whitfieldi.*

### Species referred to other Genera

The species which were originally described under *Taxocrinus,* or have been heretofore referred to it by revisors, or are so referred by me, are now distributed among the several genera as follows:

Temnocrinus. *Cyathocrinites tuberculatus* Miller.

Meristocrinus. *Cyathocrinus interbrachiatus* Ang.; *Taxocrinus orbignii* M'Coy.

Synaptocrinus. *Forbesiocrinus nuntius* Hall.

Euryocrinus. *Poteriocrinus granulosus* Phillips.

Dactylocrinus. *Dimerocrinus oligoptilus* Pacht; *Forbesiocrinus lobatus* var. *tardus* Hall; *Taxocrinus (Aristocrinus) concavus* Rowley; *Zeacrinus excavatus* Schultze.

Synerocrinus. *Taxocrinus incurvus* Trautschold.

Wachsmuthicrinus. *Forbesiocrinus spinifer* Hall; *Forbesiocrinus thiemei* Hall.

Protaxocrinus. *Lecanocrinus elegans* Billings; *Lecanocrinus laevis* Billings; *Taxocrinus austini* Ang.; *Taxocrinus distensus* Angelin; *Taxocrinus interbrachiatus* Ang.; *Taxocrinus ovalis* Ang.; *Taxocrinus salteri* Ang.; *Taxocrinus tubuliferous* Ang.

Gnorimocrinus. *Taxocrinus expansus* Angelin.

Eutaxocrinus. *Cyathocrinus brachydactylus* Roemer; *Cyathocrinus rhenanus* Roemer; *Taxocrinus affinis* Müller; *Taxocrinus curtus* Williams; *Taxocrinus fletcheri* Worthen; *Taxocrinus gracilis* Meek and Worthen; *Taxocrinus ithacensis* Williams; *Taxocrinus juglandiformis* Schultze; *Taxocrinus oblongatus* Angelin; *Taxocrinus rigens* Ang.; *Taxocrinus sturtzii* Follmann.

Taxocrinus. *Cyathocrinus* (?) *macrodactylus* Phillips; *Forbesiocrinus giddingei* Hall; *Forbesiocrinus juvenis* Hall; *Forbesiocrinus kelloggi* Hall; *Forbesiocrinus lobatus* Hall; *Forbesiocrinus ramulosus* Hall; *Forbesiocrinus shumardianus* Hall; *Forbesiocrinus whitfieldi* Hall; *Poteriocrinus nobilis* Phillips; *Taxocrinus communis* Hall; *Taxocrinus colletti* White; *Taxocrinus intermedius* Wachsmuth and Springer; *Taxocrinus interscapularis* Hall; *Taxocrinus stultus* Whidborne; *Taxocrinus ungula* Miller and Gurley.

Parichthyocrinus. *Forbesiocrinus meeki* Hall; *Taxocrinus crawfordsvillensis* Miller and Gurley; *Taxocrinus subovatus* M. and G.

Onychocrinus. *Forbesiocrinus diversus* Meek and Worthen; *Forbesiocrinus norwoodi* M. and W.; *Forbesiocrinus norwoodi* M. and W.; *Forbesiocrinus semiovatus* M. and W.; *Poteriocrinus egertoni* Phillips; *Taxocrinus polydactylus* M'Coy.

Rhopalocrinus. *Taxocrinus gracilis* Schultze.

### SYNONYMS, etc.

The following (including 3 species described as *Forbesiocrinus*) are either synonyms, insufficiently defined, imperfectly known, or do not belong to the Flexibilia:

*Taxocrinus brevidactylus* Austin (*Cladocrinites*), 1843, Ann. and Mag. Nat. Hist., XI, 198=*Poteriocrinus abbreviatus*, Rec. and Foss. Crin., 89. Insufficiently known; probably belongs to this family and might be *Eutaxocrinus*.

*Taxocrinus briareus* Schultze, 1867, Echin. Eifelkalk, 36. An Inadunate crinoid=*Lecythocrinus*.

*Forbesiocrinus cestriensis* Hall, 1860, Geol. Surv. Iowa, Supp. 68. Syn. of *Taxocrinus whitfieldi*.

*Taxocrinus grebei* Follmann, 1887, Unterdev. Crin., 6. Probably does not belong to the Flexibilia.

*Taxocrinus granulatus* Salter, 1873, Cat. Cambr. and Silur. Foss., 126. Catalogue name, not defined.

*Taxocrinus longidactylus* Austin (*Isocrinites*), 1842, Ann. and Mag. Nat. Hist., X, 108. An Inadunate crinoid.

*Taxocrinus marmoratus* Salter, 1873, Cat. Cambr. and Silur. Foss., 125. Catalogue name, not defined.

*Forbesiocrinus meeki* Quenstedt (not Hall), 1885, Handb. Petref., IV, 946; von Zittel, 1910, Grundzüge Pal., 164. Syn. of *T. colletti*.

*Taxocrinus nanus* Salter, 1873, Cat. Cambr. and Silur. Foss., 126. Catalogue name, not defined.

*Forbesiocrinus parvus* Wetherby, 1879, Jour. Cin. Soc. Nat. Hist., Oct., 1879, 5. Syn. of *Taxocrinus whitfieldi*.

*Taxocrinus pentagonus* Austin (*Cladocrinites*), 1843, Ann. and Mag. Nat. Hist., XI, 198. Insufficiently known.

*Taxocrinus priscus* (Schnur) Steininger, 1853, Geogn. Beschr. Eifel, 37. Insufficiently diagnosed.

*Taxocrinus splendens* Miller and Gurley, 1896, Bull. No. 8, Illinois St. Mus. Nat. Hist., 61. Syn. of *T. colletti*.

*Taxocrinus wetherbyi* Miller and Gurley, 1894, Bull. No. 6, Illinois St. Mus. Nat. Hist., 41. Syn. of *T. whitfieldi*.

## **Taxocrinus macrodactylus** (Phillips)

### *Plate LI, figs. 1-4*

*Cyathocrinus* ? (*Isocrinites, Isocrinus*) *macrodactylus* Phillips, Pal. Fossils Cornwall, 1841, pp. 29, 30, pl. 15, figs. 41*a-g*.

*Isocrinites macrodactylus*, Austin and Austin, Ann. and Mag. Nat. Hist., X, 1842, p. 108.

*Cladocrinites macrodactylus*, Austin and Austin, Ann. and Mag. Nat. Hist., XI, 1843, p. 198.

*Taxocrinus macrodactylus*, Morris, Cat. British Fossils, 1843, p. 59 (2d Ed., 1854, p. 90).—M'Coy, Carb. Fossils Ireland, 1844, p. 178.—Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1865, p. 138; Geol. Surv. Illinois, II, 1866, p. 270.—Wachsmuth and Springer, Revision Palaeocrinoidea, I, 1879, p. 49.—Whidborne (Devon. Foss. S. of England, III, pt. 3), Pal. Soc. London, 1899, p. 215, pl. 33, figs. 2-4*a*.—Springer, Amer. Geologist, XXX, 1902, p. 91; Jour. Geology, XIV, 1906, p. 492.

Type of the genus.

A large species. Crown very elongate, narrow; height to width, about 3.8 to 1; maximum specimen, about 90 mm. high by about 30 mm. wide. Arms strong, tapering rapidly with long divisions to five or more bifurcations. Calyx narrow, with a broad base and nearly straight sides. iBr none; areas relatively narrow, elongate. Anal side unknown. RR large. IBr 3, broad. IIBr 5 or more; IIIBr 6 to 8; IVBr 10 or more; VBr 15 or more. Surface smooth.

Column large, flush with base, expanding toward calyx; columnals very thin for the short cone at top, becoming longer downward, with but little, if any, alternation.

The description is made chiefly from the figures and descriptions given by Rev. G. F. Whidborne in his Monograph of the Devonian Fossils of the South of England. He had before him all that was left of Phillips's type specimens, viz., the original of his figure 41*e* (Palaeozoic Fossils of Cornwall, pl. 15) now in the Museum of Practical Geology, London, of which in its present condition he gives a good figure. I have copied this (Pl. LI, fig. 2), along with Phillips's original figure of the same specimen (fig. 1). Owing to the lack of technical accuracy in the older figure these appear but little alike, yet there is no doubt of the identity of the specimen. It has suffered some injury, the preservation being poor and fragile, as in many of the crinoids of the English Devonian, where they occur partly in the form of casts or natural moulds, often in rather friable material. The primibrachs below the axillary are gone, but Phillips's figure, in which there was no attempt at restoration, clearly shows that there were originally three plates below it.

I also copy another of Phillips's figures, 41*b* (fig. 3), from a specimen now lost, showing three primibrachs, and giving a general idea of the stem. Supplementing these is Whidborne's figure of another specimen (figs. 4*a, b*) which gives the characters of the stem and base. These specimens thoroughly confirm the description given by Phillips of the characters assigned to this species, the study of which led him to recognize in it a new generic type. His descriptions and accompanying remarks are as follows (Pal. Foss. Cornwall, p. 29):

> The pentagonal supra-columnar joint is surmounted by five plates (pelvis of Miller), alternately with which, and above them, are five rows of broad costal and scapular plates, four in each, the last being cuneiform. From this point, the hands and fingers go on dividing, and the number of joints in each successive branch augments. The arms, hands, and fingers are externally round; the finger ends are cirrhose.
>
> On comparing this form with *Poteriocrinus* (?) *Egertoni, Poterioc. nobilis, Cyath. tuberculatus,* &c., it appears that they are congeneric; and that, unlike other *Cyathocrinites* and *Poteriocrinites,* they might be characterized by having the scapular, costal, and cuneiform arm base in one row and of one breadth. Perhaps *Actinoc.* (?) *expansus,* of Sil. Researches, may be allied to them. If, provisionally, we designate this group by the title of *Isocrinites,* and consider the specific characters as depending on the number of plates in the costal, brachial, and digital series, we shall find
>
> *Isocrinus Egertoni,* to have seven costals;
> *tuberculatus,* three costals and three brachials;
> *macrodactylus,* four costals, five brachials, and six, ten, fifteen digitals;
> *nobilis,* four costals, four or five brachials, and four, &c., &c., digitals.
>
> It must, however, be remarked that above the costal rows the numbers of brachial and digital joints vary in the same specimen, owing to an unequal development which is almost always remarked in these fossils. In *Isoc. macrodactylus* the first digitals are six or seven. Another difference arises from age, as remarked in Sil. Researches, in relation to *Cyath. tuberculatus;* and in Geol. of Yorkshire, in regard to *Poteriocrinus.*

This description also points out the chief difference between this and the only other of his species now remaining in the genus, *T. nobilis,* viz., the longer arm divisions.

There is no mention of the anal structures, either in this or in Whidborne's redescription, as none of the specimens show them.

The geological position of the species is late in the Devonian—the Pilton beds being now classed as Upper Devonian, or at least not later than the equivalent of the Hamilton of this country.

*Types.* Phillips's original of his figure 41*e,* and that of figures 4*a, b* herein, are in the Museum of Practical Geology, London. The other specimen figured by Phillips cannot be found.

*Horizon and locality.* Upper Devonian, Pilton beds; Pilton, and North Devonshire, England.

### **Taxocrinus stultus** Whidborne

*Plate LI, figs. 5a-c*

*Taxocrinus stultus* Whidborne, Proc. Geol. Assoc., XIV, 1896, p. 377; (Devon. Fauna S. of England, III, pt. 3) Pal. Soc. London, 1899, p. 216, pl. 34, figs. 1-3.

Under this name Dr. Whidborne described a species from the same horizon and locality as *T. macrodactylus,* which is generally similar to it, except that it has a more rounded calyx and the stem does not enlarge at the top; it passes into alternating columnals below, the longer ones being convex and wider than the shorter. This difference in the stem is quite marked, and is well shown by the figures. The anal structures are visible; post. B being rather acute, followed by a series of very narrow plates of the tube, free at both sides. There is no trace of interbrachials.

*Type.* In the Porter collection, Pilton, England.

*Horizon and locality.* Upper Devonian, Pilton beds; Pilton, Devonshire, England.

### **Taxocrinus interscapularis** Hall

*Plate LII, fig. 6*

*Taxocrinus interscapularis* Hall, Geol. Surv. Iowa, I, pt. 2, 1858, p. 482, pl. 1, fig. 3.—Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1865, pp. 139, 143; Geol. Surv. Illinois, III, 1868, pp. 422, 423.—Beyrich, Monatsber. Akad. Wiss. Berlin, 1871, p. 43 (Transl. in Ann. and Mag. Nat. Hist., (4) VII, p. 401).—Quenstedt, Petref. Deutschlands, IV, 1876, p. 505, pl. 107, fig. 146.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 48.—Not Cleland, Wisconsin Geol. and Nat. Hist. Survey, Bull. 21, 1911, p. 42, pl. 3, figs. 11, 12 = *T. telleri.*

This species is only known by a single specimen, and that is in such an imperfect condition that no satisfactory detailed description can be made from it. One side is imbedded in a hard matrix, and the exposed part is much injured by weathering and accident; the base is broken off, and the basal plates described by Hall are part of the radials, according to the interpretation by my artist; it apparently has 3 IBr instead of 2, as would follow from the original description. There are two peculiar things about the specimen: (1) the high location of the iBr, supported by the $IBr_2$, instead of R as in other cases; (2) that the inner division of the IIIBr is longer than the outer. There is also a tendency in the brachials to coalesce for two or three ranges above the axillaries, which is not seen elsewhere in this genus. The species is apparently well-marked by these characters, but its relations remain obscure; and it may even not belong to this genus, as the anal side is unknown.

*Type.* Worthen collection, University of Illinois.

*Horizon and locality.* Middle Devonian, Hamilton Group; New Buffalo. Iowa

### **Taxocrinus telleri** n. sp.

*Plate LII, figs. 7-8*

*Taxocrinus interscapularis,* Cleland, Wisconsin Geol. Nat. Hist. Surv., Bull. 21, 1911, p. 42, pl. 3, figs. 11, 12.

A rather small species. Crown elongate, widest about lower IIIBr; height to width about 2.3 to 1. Calyx narrow, with curving sides; base small; height to width at IAx, 1 to 1.3; spread from base, 1 to 3. Arms tapering slowly to 3 bifurcations, with long divisions; sutures broadly sinuous. iBr few, areas rather narrow, mostly filled with perisome. Surface smooth. Dimensions of crown in adult specimen: height, 40 mm.; width, 17; base, 5.

IBB low. BB of good size with acute angles. RR and IBr large, twice as wide as long, of about the same form and size. IBr 3; IIBr usually 5. IIIBr about 14 outer and 7 or 8 inner, with one or more bifurcations visible; arms infolding beyond this with very long finials. Anal series composed of elongate plates, their full structure not known. Column unknown.

This species is proposed for some Hamilton specimens from Milwaukee, which I was unable to refer satisfactorily to any known species. They were found by Mr. E. E. Teller of that city, a business man who is a keen observer and ardent lover of science, and whose name I have pleasure in associating with the species. The nearest related form is *T. interscapularis* from the Iowa Hamilton, which differs in the number of IIBr and in the arrangement of IIIBr. The small specimen figured (Pl. LII, figs. 8*a-d*) is a remarkable variation from the normal crinoid. It has 7 rays; one with 3 IBr, and six with 2, in one of which the R is split vertically. The basal ring, IBB and BB together, is fused into a single solid plate. According to the number of primibrachs in most of the rays it would belong to *Eutaxocrinus;* but in view of its great irregularity this may not prove anything, and as the specimen was found associated with the fine adult specimen (figs. 7*a, b*), I have placed it here to illustrate a striking example of abnormal growth.

*Type.* Collection of Mr. E. E. Teller, of Milwaukee, Wisconsin;—a careful and intelligent collector, to whom I am indebted for valuable information.

*Horizon and locality.* Middle Devonian, from an outlier of the Hamilton group; near Milwaukee, Wisconsin.

### **Taxocrinus lobatus** (Hall)

*Plate LII, figs. 9-11*

*Forbesiocrinus lobatus* Hall, 15th Rep. New York St. Cab. Nat. Hist., 1862, p. 124; Bull. I, New York St. Mus. Nat. Hist., Photographic Plates, pl. 1, fig. 11.

*Taxocrinus lobatus,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 49.—Wood. Smithsonian Misc. Collections, XLVII, 1904, p. 81.

Not *Taxocrinus lobatus* var. Whiteaves, Contrib. Canadian Pal., I, pt. 2, 1889, p. 94, pl. 12, fig. 1.

A medium-sized species. Crown elongate, turbinate below; height to width at second axillaries, 1.9 to 1. Calyx narrowly spreading, 1 to 3, with nearly straight sides; height to width at IAx, 1 to 1.4. Arms large and deeply rounded, strongly divergent, tapering very gradually, the first division series being almost as large as the primibrachs; infolding about the fourth bifurcation, but much longer and bifurcating further beyond; sutures strongly arcuate, and a strong node on each axillary. iBr spaces wide, chiefly filled with strong perisome. Anal tube large and prominent. Surface smooth. Crown of mature specimen, 41 mm. high; 22 wide; base, 6 mm.

IBB low but showing well above the column. BB fairly large, with acute angles. Post. B extremely large and broad with very wide concave socket, supporting a large anal tube with lower plates large, as wide as high, becoming shorter above, and bordered on both sides with wide areas of very strong perisome. RR and IBr of similar form and size, almost as long as wide. IBr 3, exceptionally 2; IIBr usually 4, sometimes 5, nearly as wide as IBr. IIIBr 6 on inner and about 8 in outer division. iBr 1 to 3, and small iIIIBr sometimes present, followed by extensive perisome. Column unknown.[1]

The brachials throughout in this species are much longer than is usual for the genus, and the development of anal structures and perisome much more profuse than in any other Devonian species, recalling those of the later Subcarboniferous. In arm structure it superficially resembles *T. kelloggi,* but it has a much narrower and more conical calyx, and is very different in other details. The type specimen is in poor condition, and does not show the structures plainly; it seems, however, to have but two IBr in part of the rays, whereas the other two extremely well-marked specimens have three consistently throughout. One of these (fig. 10) shows all the characters of the species most beautifully; and the other (fig. 11), though not so perfect, fully confirms it. The latter has a Gasteropod commensally attached over the anus.

*Types.* Hall's original (fig. 9) is in the American Museum of Natural History, New York; that of figure 10 in the New York State Museum, Albany; and that of figures 11*a, b* is in the author's collection.

*Horizon and locality.* Middle Devonian, Moscow shales of the Hamilton group; Canandaigua Lake, New York.

## **Taxocrinus communis** (Hall)

*Plate LII, figs. 1-4*

*Forbesiocrinus communis* Hall, 17th Rep. New York St. Cab. Nat. Hist., 1863, p. 6 (Separate); Final Report, 1864, p. 55.—Hall and Whitfield, Geol. Surv. Ohio, II, Pal., 1875, p. 169, pl. 12, fig. 3, not figs. 4, 5.

*Taxocrinus communis,* Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, IX, 1865, pp. 140, 141; Geol. Surv. Illinois, II, 1866, p. 270.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 48.

A small species, with elongate crown, and a very peculiar stem; height to width at second axillary, 1.4 to 1. Calyx greatly expanding, obconical below, with narrow base and concave sides; height to width at IAx, 1 to 1.4; spread from base, 1 to 2.5. Arms heavy, rounded, tapering slowly, with not over three bifurcations before infolding; iBr few, spaces narrow and elongate. Surface smooth.

IBB low, visible as a short ring. BB small, fairly acute-angled. RR and IBr of similar form, about half as long as wide, increasing in width to the axillary. IBr 3; IIBr 4 or 5, of about equal size, with one more division on inner ramus at about 9th brachial in mature specimens, but not in younger.

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[1] See explanation of Plate LII, figs. 9-11.

Anal tube not preserved, but evidently small, resting on narrow post. B. iBr 1, small. Column next to calyx strong, composed of thin columnals which after a short interval begin to enlarge in diameter downward instead of diminishing, soon changing rather suddenly to much longer, convex ossicles; these increase in length and width for some distance, and then diminish, becoming narrower and more uniform toward the end, which is not preserved. Dimensions of medium specimen with nearly complete stem; crown, 20 mm. high by 14 mm. wide; base, 4 mm.; calyx, 7 mm. high by 10 mm. wide at IBr$_3$.

The peculiar median swelling of the stem is the most interesting feature of this species; it is plainly shown in the type, but much better by the beautifully perfect specimen in my own collection. It may be compared with *Eutaxocrinus ithacensis* as to the stem, in which, however, there are distinct differences. In the young specimens the distal increase in the stem is not apparent so far as preserved. The species is one of the earliest Carboniferous occurrences of the genus, being found in the same locality and beds immediately succeeding the Devonian with *T. kelloggi,* from which it is thoroughly distinct.

Hall figured under this species three specimens, of which only the first one, figure 3 of the Ohio Report, belongs here. The others, Palaeontology of Ohio, plate 12, figures 4 and 5, must go under *Forbesiocrinus.*

*Types.* Hall's original, Plate LII, figure 1 herein, and those of figures 2 and 3, are in the New York State Museum, Albany; that of figure 4 is in the author's collection.

*Horizon and locality.* Lower Carboniferous, lowest part of Waverly group, Cuyahoga shales; Richfield, Ohio.

## **Taxocrinus kelloggi** (Hall)

*Plate LII, figs. 5a-c*

*Forbesiocrinus kelloggi* Hall, Prelim. Notice 17th Rep. New York St. Cab. Nat. Hist., 1863, p. 7; Final Rep., 1864, p. 56.—Hall and Whitfield, Geol. Surv. Ohio, Pal., II, 1875, p. 171, pl. 12, fig. 1.

*Taxocrinus kelloggi,* Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1865, p. 140; Geol. Surv. Illinois, II, 1866, p. 270.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 49.

A small species, with elongate crown and broad, low base; height to width at second axillary 1.6 to 1. Calyx broadly rounded below, spreading rapidly to radials, thence but little to IAx; spread from base to middle of RR, 1 to 2.2; from RR to IAx, 1 to 1.2. IBr diminishing upward. Arms heavy, deeply rounded, tapering but little, and strongly divergent leaving wide iBr spaces; bifurcating three times before infolding, with strong nodes on the axillaries; sutures arcuate. Surface otherwise smooth. Height of crown, 21 mm.; width, 13 mm.; base, 4 mm.

IBB low, visible; BB small, acute-angled. RR the largest plates in the calyx. IBr smaller, and narrowing upward to the axillary, which is about as wide as the next preceding plate. IBr 3; IIBr 5; IIIBr 5 to 7. Anal tube slender, composed of elongate plates; iBr 1, followed by perisome. Column large at calyx, with very thin columnals, tapering gradually, with alternate ossicles becoming longer and convex.

This species is readily distinguished from *T. communis,* its fellow of the same horizon and locality, by its large radials and diminishing primibrachs, and the consequent broadly rounded calyx; wide interbrachial spaces, and nodes upon the axillaries; also by the form of the stem. It is more nearly like *T. lobatus* of the Devonian, which has the same nodose axillaries and heavy arms, but differs in the smaller radials and the very large anal tube.

*Type.* But a single specimen is known, and that is in the New York State Museum, Albany, New York.

*Horizon and locality.* Base of the Lower Carboniferous, lower part of Waverly group, Cuyahoga shales; Richfield, Ohio.

### **Taxocrinus intermedius** Wachsmuth and Springer

*Plate LIII, figs. 1-6*

*Taxocrinus intermedius* Wachsmuth and Springer, Proc. Acad. Nat. Sci. Philadelphia, 1888, p. 344, pl. 18, figs. *1a-e;* Geol. Surv. Illinois, VIII, 1890, p. 199, pl. 15, fig. 11; N. A. Crinoidea Camerata, 1897, pl. 3, fig. 11, pl. 8, figs. 5*a, b.*—Von Zittel, Grundzüge Palaeontologie, 1895, p. 138, fig. 272.—Zittel-Eastman, Textbook Paleontology, 1896, p. 164, fig. 272 (2d Ed., 1913, p. 178, fig. 276, and p. 206, fig. 306).—Bather, Geol. Mag. (Dec. IV), V, 1898, p. 524; Treatise on Zoology (Lankester), pt. 3, 1900, p. 126, fig. 37.

A large species. Crown low, broad and massive, broadly rounded below; height to width at about IIBr$_3$ 1.2 to 1. Calyx relatively low, hemispheric, height to width at IAx, 1 to 2. Spread from column facet, 1 to 3.3; side outline evenly convex. Rays broad, and not projecting above level of iBr. Arms heavy below, tapering rapidly from IIBr to small finials, with short divisions to four bifurcations beyond which they infold. Sutures moderately sinuous. iBr numerous, large, and about flush with rays; areas not depressed. Surface smooth. Dimensions of large normal specimen: Crown, 42 mm. high by 35 mm. wide; base, 10 mm.

IBB low, barely visible beyond column. BB fairly large; post. B high and much wider than others, encroaching on space of r. post. R which is smaller than its fellows. RR over twice as large as BB, and nearly twice as wide as long, except r. post. R, which is reduced in width by encroachment of first plate of anal series. IBr 3, exceptionally 2, similar to RR, continuing about the same size and nearly uniform except for the axillary IBr 3; IIBr 3, exceptionally 4, large, not diminishing upward. IIIBr 3 or 4 inner, 5 or 6 outer; brachials 5 or 6 to 8 or 9 in next division; the last two divisions diminishing in size rapidly from one bifurcation to another, and having very short brachials. Anal tube relatively rather small, composed of plates about as long as wide, connecting at each side with finely plated perisome; first plate large, resting in a deep socket at right side of post. B and encroaching on r. post. R. iBr consisting of a number of large plates, having a crescentic distal margin curving to the rays at about the top of the first axillary; they are succeeded by fine perisome connecting at the inner distal margin, and extending like a pouch high up the rays to about the upper IIBr; similar heavy iBr plates in less number occur in the second and third axils. Column large, flush with the infrabasal ring; composed near the calyx of very thin columnals and as far as known tapering rapidly downward.

This species is notable for being the one in which the true structure of the tegmen in the Flexibilia was discovered. An elaborate description of it was given by Wachsmuth and Springer in 1888, and their figure of the principal specimen has been repeatedly copied in general works on paleontology. I give a somewhat better figure of the ventral side, enlarged to two diameters (Pl. LIII, fig. 1*b*). The tegmen consists of a thin and pliant skin, thickly paved with small calcareous plates in close contact, but without definite arrangement. At the oral center there is an open mouth surrounded by five large unsymmetrical parted oral plates, elliptic in outline and of three sizes. The posterior oral is very much the largest, the two anterior less than half as large, and the two lateral orals again scarcely half as large as the latter; these plates are all quite thick, and the smaller ones, from which the perisome has somewhat fallen away, stand out like pegs. Five large, strongly plated ambulacra, with short, interlocking covering plates, pass out from the mouth between the orals, bifurcating over the radial axillaries, and traversing the perisome to about the lower IIIBr—thus giving two bifurcations before the arms become free. The anal series of plates is attached to the perisome at the posterior side and finally merges in it; the folds in the perisome where the tube is pushed to one side can be well seen in figure 1*a*.

The specimen in which these structures are so beautifully preserved was obtained by Wachsmuth and myself in the summer of 1888, when upon a collecting expedition at the extensive quarries in the Kinderhook limestone at Legrand, Marshall County, Iowa. It has been slightly compressed vertically, and as discovered the rays were broken off; the upper part of the specimen was imbedded in a very fine-grained, perfectly homogeneous deposit of firm, calcareous mud. The favorable position of the expanded rays, coupled with the unusually fine preservation of the crinoids of that locality, encouraged the hope that we might have here the means of ascertaining the actual ventral structure of this group, as to which there had been much and diverse speculation. This hope was realized after long and patient cleaning of the specimen by removing the matrix with fine tools under a strong magnifier; and the result was a complete modification of previously prevailing views as to the essential tegminal structure of the Flexibilia and the classification of the group, as was set forth in the publication which followed. It is rare in the history of paleontology that the discovery of a single specimen has thrown such a flood of light upon the larger questions affecting a given group. The character and extent of the perisome, without the ventral structures, are well shown in the three other large specimens figured on Plate LIII. The sutures in several of the specimens do not appear to be very sinuous in the lower parts; this is largely due to the effect of cleaning from a very fine adherent matrix, and to the unusual thinness of the patelloid projections in this species; but the usual structure prevailed to a moderate degree.

This species marks the opening of a line of development in *Taxocrinus,* characterized by a profusion of strong interbrachial plates forming an essential part of the calyx wall, which continued through a number of well-marked and abundant species until the extinction of the genus. The last three small species surviving in the Warsaw to Kaskaskia are very much like it in habitus. It exhibits some variability in the construction of the calyx as to the generic character based upon the number of primibrachs, some specimens having in part of their rays only 2 IBr instead of 3. This instability looks more formidable in the figures than it really is, because the specimen showing it most conspicuously happens to be very thoroughly figured (Pl. LIII, figs. 2*a, b, c*). In six specimens in which 24 rays are exposed, 18 of them have 3 IBr, and 6 have 2, and in the latter there is a tendency to compensate for the deficiency in IBr by an increase of IIBr; out of 42 rami showing the IIBr, 34 have 3, and 8 have 4. Hence there can be no doubt that the normal structure in the species is 3 IBr and 3 IIBr.

Upon the mere statement of diagnostic characters the species does not appear so very different from *T. ramulosus* of the Upper Burlington, but with the specimens or the figures for comparison they could never be confounded. The massiveness of the calyx compared with the smallness and rapid tapering of the free arms, and the almost even curvature of the calyx wall without depression at the interbrachial areas, are entirely characteristic; while the peculiar reduction in width of the right posterior radial caused by the large size of the posterior basal and the low lateral position of the first anal plate is unusual among Carboniferous species, suggesting a migration of the radianal from the primitive position among the more ancient forms.

*Types.* The first publication of the name of the species, with a complete description and figures of specimens, was in the Proceedings of the Philadelphia Academy of Natural Science in 1888, although a description, with a figure of another specimen, had been previously prepared by the same authors for volume 8 of the Reports of the Geological Survey of Illinois. The Illinois Report did not appear until 1890. Therefore the types of the species are the specimens figured in 1888, viz., the originals of figures 1, 2 and 3 of Plate LIII herein, which are in the author's collection; as are also those of figures 5 and 6. The fine specimen figured in the Illinois Report, and refigured here (fig. 4), is in the Walker Museum, University of Chicago.

*Horizon and locality.* Base of the Lower Carboniferous, Kinderhook group; Legrand, Marshall County, Iowa.

## **Taxocrinus pustulosus** n. sp.

*Plate LIV, figs. 19-20*

I have figured under this name a strongly ornamented species occurring at various localities in the Knobstone of Kentucky and Indiana, of which only the arms and detached fragments have as yet been found; the calyx is entirely wanting. It is a large species, with heavy, deeply rounded arms tapering slowly for four or five bifurcations, somewhat similar to *T. ornatus* of the Lower Burlington; but it is distinguished by having the surface throughout covered with sharp, closely placed pustules, instead of wrinkles on the arms as in the Burlington species. A number of fragmentary specimens have been found showing the characters of the arms, and the ornamentation is very prominent and constant.

*Types.* Author's collection.

*Horizon and locality.* Lower Carboniferous, New Providence shales of the Knobstone Group; near Henryville and other localities in Clark County, Indiana; Button Mould Knob. Kentucky.

### **Taxocrinus juvenis** (Hall)

*Plate LIV, figs. 3-11*

*Forbesiocrinus juvenis* Hall, Boston Jour. Nat. Hist., VII, 1861, p. 319; Prelim. Descr. new species Crinoidea, 1861, p. 8; Bull. I, New York St. Mus., Photographic Plates, 1872, pl. 7, fig. 3.

*Taxocrinus juvenis,* Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1865, p. 140; Geol. Surv. Illinois, II, 1866, p. 271.—Wachsmuth and Springer, Revision Palaeocrinoidea, I, 1879, p. 49.—Whitfield, Mem. Amer. Mus. Nat. Hist., I, 1893, p. 35, pl. 3, figs. 21, 22.

A variable species, usually of small size. Crown elongate, turbinate below, with narrow base; height to width at second axillary, 1.5 to 1. Calyx to IAx almost as high as wide, about 1 to 1.1; spread from base, 1 to 2.8, with side outline gently curving. Arms tapering rapidly from IIBr to fine extremities, infolding usually about the third bifurcation; sutures broadly sinuous to arcuate. iBr spaces wide, plates small passing into a strong perisome. Surface smooth. Dimensions of type: crown, 18 mm. high by 11 mm. wide; base, 3 mm.; an unusually large specimen is 33 mm. high by 18 mm. wide, but the average of seven specimens as usually found is about 13 mm. high by 9 mm. wide.

IBB low, visible; BB fairly large. RR and IBr about twice as wide as long, of similar form and size throughout. IBr 3; IIBr usually 4, sometimes 3 in part of the rays, of nearly uniform size. Higher brachials in rather long divisions diminishing rapidly at each bifurcation. iBr small in average specimens, with strong perisome in larger ones. Column large, long, slightly enlarging at calyx and passing into long, nearly uniform columnals a short distance below; in a small specimen of average size, not figured, it is 170 mm. long, with almost uniform columnals about as long as wide throughout its entire length below the upper 25 mm.

This species is readily distinguished from the other Lower Burlington *Taxocrinus* by its perfectly smooth surface and rapidly tapering arms; less easily in superficial appearance from *T. ramulosus* of the Upper Burlington, especially in young specimens with the interbrachials little developed; that, however, is of a decidedly shorter habitus, having usually 3 IIBr, and its interbrachial system is much farther advanced. *T. juvenis,* though generally of an elongate tendency, shows some variation in the number of lower brachials, some specimens having 3 IIBr in part of the rays, and one (fig. 9) has only 2 IBr all around. It is characteristically a small-sized species. I have twelve specimens, averaging about like those of figures 3-9. Figure 10 shows an extremely mature specimen, as indicated by the crowded condition of the interbrachial areas, and no other nearly so large has been seen. The specimen figured 11*a*, *b* is an interesting example of the modification of shape caused by accidents in fossilization; from figure 11*a* alone one would suppose, as I did, that with so very short and broad a calyx it must belong to a different species from the elongate forms accompanying it; but I found that this was mainly due to accidental expansion caused by pressure of a large stem fragment which has pushed in the entire opposite calyx wall, as shown in figure 11*b*. The originals of figures 10 and 11 are much weathered, and the patelloid sutures to a large extent obliterated.

In the Memoirs of the American Museum of Natural History, volume 1, part 1, being a "Republication of descriptions of Lower Carboniferous Crinoidea from the Hall collection in the American Museum, with illustrations of the original type specimens not heretofore figured," plate 3, figures 21, 22, Professor Whitfield figured a specimen without arms as the type of the species. This was an error. The type specimen, as stated by Hall (Boston Journal, vol. 7, p. 320) was in the collection of the Rev. W. H. Barris, which was acquired afterward from him by the Museum of Comparative Zoology, Harvard, and is the one figured herein (Pl. LIV, fig. 3). It bears the label with the original number as received from Dr. Barris, in Whitfield's handwriting, and a figure of it drawn by him was reproduced by Hall as plate 7, figure 3 in the Photographic Plates printed in 1872 under title of State Museum Nat. Hist., Bull. I.

*Type.* Collection of Museum of Comparative Zoology as above stated.

*Horizon and locality.* Lower Carboniferous, Lower Burlington limestone; Burlington, Iowa.

### **Taxocrinus ornatus** n. sp.

*Plate LIV, figs. 12-13*

A large sized species. Crown elongate, moderately spreading below; height to width at about the eighth axillary 1.7 to 1. Calyx at IAx, 1 to 2.6, with spread from base in same proportion. Arms long, strong, tapering very slowly with relatively short divisions to four bifurcations, with another division in the outer rami, beyond which the arms infold in coils of several whorls; sutures strongly arcuate. iBr spaces wide, with few plates. Surface of calyx plates and lower brachials covered with thinly scattered pustules, which become confluent in the arms, forming distinct longitudinal parallel wrinkles on all the higher brachials. Dimensions of crown in principal type specimen: height, 50 mm.; width, 29 mm.; base, 8 mm.

IBB not preserved, probably low; BB low pentagons with obtuse angles. RR and IBr of similar form and size, about two and one-half times as wide as long, slightly increasing upward (a plate wanting in one ray). IBr 3; IIBr usually 4, slightly diminishing upward: IIIBr 5 or 6 inner and 7 or 8 outer; IVBr 8 or 9 outer and 12 or 15 inner, with at least one more division in the outer rami at about the fifteenth brachial. iBr 3 or 4, small with small iIIBr also present. Anal tube and column unknown.

The high ornamentation of the arms distinguishes this species from all the preceding, as well as from others in the Burlington limestone. It is very rare; only one fragment has been found in all the collections in addition to the beautiful type shown by figures *12a, b.*

*Types.* Author's collection.

*Horizon and locality.* Lower Carboniferous, Lower Burlington limestone; Burlington, Iowa.

### **Taxocrinus nobilis** (Phillips)

*Plate LIV, figs. 1a-c*

*Poteriocrinus ? nobilis* Phillips, Geology Yorkshire, II, 1836, p. 205, pl. 3, fig. 40.—(*Poteriocrinites*) Goldfuss, Nova Acta Acad. Leop. Carol-Nat. Cur., XIX, 1839, p. 351.—D'Orbigny, Prodr. Pal. Stratigraphique, I, 1849, p. 157.—(Troost MS.), Wood, Bull. 64, U. S. Nat. Mus., 1909, p. 82.

*Isocrinites nobilis* Phillips, Pal. Fossils Cornwall, 1841, p. 30.—Austin and Austin, Ann. and Mag. Nat. Hist., X, 1842, p. 108.

*Cladocrinites nobilis,* Austin and Austin, Ann. and Mag. Nat. Hist., XI, 1843, p. 197.

*Taxocrinus nobilis,* Morris, Cat. British Fossils, 1843, p. 59 (2d Ed., 1854, p. 90).—Geinitz, Verstein. Grauwacken Formation in Sachsen, 1853, p. 72, pl. 20, fig. 11.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 3, 1886, p. 144.—Whidborne, Mon. Devon. Fauna S. of England, III, pt. 3, Pal. Soc. London, 1899, p. 216.—Springer, Amer. Geologist, XXX, 1902, p. 91; Jour. Geology, XIV, 1906, p. 492.

*Cyathocrinus nobilis,* Roemer in Bronn, Lethaea Geognostica, I, 1852-54, p. 236.

*Dimerocrinites nobilis,* Pacht, Beitr. Kenntn. Gattung *Dimerocrinites,* 1852, p. 7.

A very large and massive species. Crown subturbinate, almost as broad as high, expanding gradually to about the level of the first IVBr, where height to width is about 1.2 to 1. Calyx 1 to 1.3 at IAx, with spread from base of 1 to 1.2. Arms very heavy, deeply rounded, tapering but little, and diminishing much less than half at the bifurcations; divisions rather short to the third bifurcation, infolding about the fourth; sutures broadly sinuous. iBr few and small, and areas narrow. Anal tube small. Surface smooth or finely tuberculose. Dimensions of crown in type: height, 53 mm.; width, 45 mm.; base at column facet, 10 mm.

IBB small, hidden by column, and within the basal ring. BB small, appearing in low pentagons beyond the column; post. B narrow above, with a small excavated socket for support of first plate of the anal series. RR and lower IBr rather similar in form and size, increasing gradually in width to the axillary which is still wider. IBr 3; IIBr 4 or 5, nearly as wide as IBr, and over three times as wide as long; IIIBr 5 or 6, and 7 or 8, about two-thirds as wide as IIBr and of similar proportions; higher divisions diminishing in about the same proportion. Anal area larger than the others; tube evidently small, socket not encroaching on adjacent radials. iBr a few small, elongate plates in narrow areas. Column not preserved, but facet large, as wide as the truncate base.

The arms of this species are ponderous for this group, and by having the brachials of each order more than half the size of their predecessor the rays increase in width in each division, filling up the spaces; this leaves little room for interbrachials, and causes the crown to continue expanding almost until the arms infold. The species bears little resemblance to any other, the one that seems actually nearest being that represented by some imperfect sets of arms, which I have named *T. pustulosus,* from a substantially equivalent horizon of the American Lower Carboniferous. *T. nobilis* was identified by De Koninck and Le Hon with the specimens from the Belgian Mountain limestone on which they founded their genus *Forbesiocrinus;* but they were doubtless led to this by the strong rays, for the specimens are not otherwise similar, even generically. This is fully discussed under *Forbesiocrinus,* where the reasons for this opinion are shown in detail.

I have, however, in recent years obtained a specimen from the Tournai limestone of Belgium (Pl. LIV, figs. *2a, b*) which is a true *Taxocrinus,* and which according to the notions of species prevailing in De Koninck's time would be referred to *T. nobilis* without the least doubt, as in fact I did when it was first obtained. It now seems impossible to maintain the identity of the two forms owing to the condition of the infrabasals in the type, which are entirely within the ring of basals—the character on which I founded one of the families in the other large division of the Flexibilia. I have not found another case so pronounced as this among the Taxocrinidae, and therefore consider it a variation from the normal. With a number of specimens we might find intermediate stages, but having only the one, so thoroughly well preserved as Phillips's type, we can scarcely ignore this as a specific character. I have therefore separated the Belgian form, chiefly on this character although there are some others.

*Type.* In the Gilbertson collection, British Museum of Natural History, London. The specimen is unique.

*Horizon and locality.* Lower part of the Lower Carboniferous, or Mountain limestone, equivalent to the Lower Burlington—Choteau—Knobstone of the United States; Yorkshire, England.

### **Taxocrinus belgicus** n. sp.

*Plate LIV, figs. 2a, b*

A small species founded upon the specimen from the Belgian Lower Carboniferous mentioned under *T. nobilis,* which I have separated chiefly because it has the infrabasals visible outside the column and upon the dorsal side of the basals instead of within them. It also differs in the greater width of the posterior basal, and more convex form of the calyx. The specimen is small, less than half the size of the other—the figure being enlarged to two diameters. It is notable for being the only example of true *Taxocrinus* thus far discovered in the Belgian rocks.

*Type.* Author's collection.

*Horizon and locality.* Lower Carboniferous, Tournai stage; Tournai, Belgium.

### **Taxocrinus ramulosus** (Hall)

*Plate LIV, figs. 14-18*

*Forbesiocrinus ramulosus* Hall, Supplement Geology Iowa, 1860, p. 67.
*Taxocrinus ramulosus,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 49.
*Forbesiocrinus subramulosus* Shumard, Trans. Acad. Sci. St. Louis, II, 1866, p. 372.

A medium-sized species. Crown low and broadly subturbinate, with strongly prominent rays; almost as wide as high at the IIIBr; height to width of average specimen, 1.2 to 1. Calyx to IAx broadly pentagonal; height to width, 1 to 2, with spread from base of 1 to 3.6. Rays relatively narrow below, strongly convex and raised above the level of adjacent plates; arms strongly divergent, not tapering rapidly until beyond the third bifurcation, where they infold; divisions rather short. Sutures but little sinuous except in the higher brachials. iBr numerous, areas broad and depressed below level of rays. Surface smooth. Dimensions of crown in adult specimen: height, 25 mm.;

width, 21 mm.; base at column facet, 4.5 mm.; maximum specimen, 30 mm. high by 24 mm. wide.

IBB very low, barely visible. BB fairly large; post. B not greatly exceeding the others and not encroaching on r. post. R. RR and IBr except the axillaries similar in size and form, less than twice as wide as long, without marked taper; R somewhat the largest. IBr 3; IIBr usually 3, about uniform, the divisions being at a wide angle; IIIBr 4 or 5, and 7 or 8. Anal tube rather small, composed of plates somewhat longer than wide, the first one not materially encroaching on r. post. R. iBr numerous, extending into the second and third axils, the distal margin of primary area concave and curving to meet the brachials; plates in all areas more or less depressed below level of brachials. Column of the common type for the genus, enlarging at the calyx with very thin columnals, and diminishing downward with the alternate columnals becoming longer.

The tegmen in this species extends high up between the IIIBr, the development of iBr in this respect being more extensive than in any other species of similar size. In strictness that should be considered the limit of the calyx, but to facilitate comparison I continue to measure it at the arbitrary height of the top of the first axillary. The species is perhaps nearest to the antecedent *T. intermedius* of the Kinderhook, and is in the same line of development; but the whole habitus is different, and with its widely divergent arms, low interbrachial areas and highly rounded rays, it is readily distinguished from that species. It is not so easy to point out good characters to distinguish it from *T. giddingei* of the Warsaw limestone, which will be considered under that species. The possession of a good series of specimens enables me to show that in this Burlington species the 3 IBr of the typical *Taxocrinus* had become well established, for among 16 there is no departure from the rule. Tabulation of the data from these also shows that with slight exceptions the 3 IIBr is the normal character for this species, in contrast with *T. juvenis* of the Lower Burlington with 4 or 5; in other words it is essentially a shorter form. Among the 16 specimens in hand, 97 rami are exposed having IIBr as follows: with 2, 5; 3, 75; 4, 17; that is to say, 82 per cent have 3 IIBr or less; and in no specimen are there 4 in all the rays. It happens that a specimen probably studied by Hall had 4 IIBr in some rays, and he so described the species.

This species was first described by Hall, without figure, under *Forbesiocrinus*. Shumard in his Catalogue of 1866, having first assumed that *Onychocrinus* was a synonym of that genus and having therefore placed the *O. ramulosus* of Lyon and Casseday under *Forbesiocrinus*, found that he had two species under the same name; so he proposed *F. subramulosus* for the present form. But as it is clear that neither belongs to the genus under which he listed them, Shumard's proposed name must give way to the original. As above indicated, the species is well represented, and was well known to all the early Burlington collectors as the one described by Hall. Good specimens are in the Museum of Comparative Zoology, Harvard, and other collections.

*Types.* The species was never figured, and the record of Hall's original is lost. There is a specimen in the Worthen collection, University of Illinois, among other types which were studied by Hall, and this is probably the type, but there is no way of determining it. The other specimens figured and used in the study are in the author's collection.

*Horizon and locality.* Lower Carboniferous, Upper Burlington limestone; Burlington, Iowa.

### **Taxocrinus ungula** Miller and Gurley

*Plate LV, figs. 1-10*

*Taxocrinus ungula* Miller and Gurley, Bull. 8, Illinois St. Mus. Nat. Hist., 1896, p. 59, pl. 5, figs. 1, 2.

A large species. Crown short, broad, turbinate, widely spreading to fourth bifurcation, with rays very conspicuous; height to width 1 to 1. Calyx obconical, with nearly straight sides; height to width at IAx, 1 to 2; spread from base, 1 to 2.4. Rays and their divisions deeply convex and prominent, usually diminishing markedly at the IIIBr, and bifurcating by wide angles, like the claws of a bird; beyond this the arms are strong, tapering slowly, and with rather long divisions; sutures strongly arcuate. iBr numerous, spaces wide and depressed. Surface smooth. Dimensions of crown in large mature specimen: height, 54 mm.; width, 48 mm.; base, 15 mm.; in young specimen: height, 10 mm.; width, 13; base, 3.

IBB very low, forming a flat ring like a thickened columnal; without salient angles visible externally. BB of good size, with acute angles; post. B large and broad, with large socket on right shoulder for first anal plate. RR and IBr not markedly differing in size, diminishing slightly upward, about twice as wide as long. IBr 3; IIBr 3, almost as large as the preceding; IIIBr about 4 and 6, of even size, two-thirds as large as IIBr and over twice as large as the plates following, with little diminution in the next succeeding division. Anal tube large and long, the plates rather shorter than wide, and bordered with coarsely plated perisome which at the bottom may resemble regular interbrachials; first plate often wide, encroaching somewhat on r. post. R. iBr strong and profusely developed to the upper IIBr, with crescentic distal margin, and wide areas depressed below level of the rays; similar and successively smaller plated areas occur in the second and third axils, separating the brachial divisions by wide angles. Column large, flush with the base; proximal columnals extremely thin, diminishing in diameter slowly until they alternate with longer ones.

The claw-like appearance of the rays is a marked and constant character of this fine species, by which it can be recognized from imperfect fragments. The form is a further development of the habitus of *T. ramulosus,* of which it may well be the lineal descendant. It is remarkably constant in all its characters, as shown by a magnificent series of 17 finely preserved specimens, varying from maximum adults upwards of 50 mm. in height and width to the young of only 10 mm. in height in which the turbinate form is equally conspicuous. The contrast with *T. colletti* in this respect is well shown by a young specimen on Plate LV, figure 11. There is practically no variation in the number of IIBr; in the sixteen specimens 144 rami are visible, and of these only five have more than 3 IIBr. Figures 6 and 7 of Plate LV show the only variations observed, being the less conspicuous diminution of the arms at the IIIBr, and greater elongation of these plates. The increase of interbrachials from the young to adult stage is well shown by these specimens.

*Types.* Miller and Gurley's original is in the Walker Museum, University of Chicago. The other specimens figured and used in study are in the author's collection.

*Horizon and locality.* Lower Carboniferous, Keokuk Group; all from two colonies at Indian Creek, Montgomery County, Indiana, at a horizon below that of the Crawfordsville bed.

### **Taxocrinus colletti** White

*Plates XXI, fig. 4; LV, fig. 11; LVI, figs. 1-11; LVII, figs. 1-10*

*Taxocrinus multibrachiatus* var. *colletti* White, 2d Ann. Rep. Stat. and Geol. Indiana, 1880, p. 506, pl. 6, fig. 3 (another edition 1881, p. 138).

*Taxocrinus colletti,* Miller and Gurley, Bull. 3, Illinois St. Mus., 1894, p. 49; *ibid.*, Bull. 8, 1896, p. 56.—Zittel-Eastman, Textbook Paleontology, 1913, p. 206, fig. 307.

*Forbesiocrinus meeki,* Quenstedt (not Hall); Handbuch Petrefaktenkunde, 1885, p. 946, pl. 75, figs. 24, 25.

*Taxocrinus meeki,* Von Zittel (not Hall), Grundzüge Palaeontologie, 1895, p. 138, fig. 273; Zittel-Eastman, Textbook Palaeontology, 1896, p. 164, fig. 273.

*Taxocrinus splendens* Miller and Gurley, Bull. 8, Illinois St. Mus., 1896, p. 61, pl. 5, figs. 3, 4; Springer, Jour. Geology, XIV, 1906, p. 489.

*Taxocrinus multibrachiatus* collectionum.

Not *Forbesiocrinus multibrachiatus* Lyon and Casseday, Amer. Jour. Sci. (2) XXVIII, 1859, p. 235.

A representative and highly characteristic species of the genus *Taxocrinus.* Specimens attaining a large size. Crown elongate, moderately rounded below, widest about the third bifurcation, and usually infolding shortly above the fourth; height to width about 1.4 to 1. Calyx 1 to 2.5 at IAx in average large specimen; in smaller ones narrower, 1 to 1.2; spread from base, 1 to 3.2. Rays strong and prominent, broadly convex in lower divisions; arms tapering evenly and without marked change until beyond the third axillary, and not strongly divergent; sutures strongly arcuate. Interbrachials well-developed; areas depressed, fairly wide, elongate, with numerous strong plates in lower portion. Surface covered with a very close pustulose or sometimes slightly wrinkled ornamentation. Dimension of representative large specimen: Crown, 54 mm. high; 35 mm. wide; base, 9 mm.; calyx, 11 mm. high by 28 wide. Small specimens: Crown, 10 mm. high by 7 wide; base, 3; calyx, 6 by 6.5 mm.

IBB very low, not within BB, but visible only as a thin line like a top columnal. BB small, less than half the size of RR, low, and obtuse-angled except post. B; this plate is very high, its distal margin well rounded in a dorso-ventral direction, with a shallow scar for attachment of first one or two anal plates extending more than half-way down its outer surface; usually rather to the right of the median line, but not encroaching on r. post. R. RR about the form and size of succeeding IBr, which are half as long as wide. IBr 3; IIBr 3 in most cases, frequently 4, nearly as large as IBr and of similar form; IIIBr 5 or 6 inner, 8 or 10 outer; the next division proportionally larger. Brachials above IIBr proportionally shorter than below, being often only one-third as long as wide. iBr 6 to 10 strong plates, with rounded and crescentic distal margin connecting with finely plated perisome at the inner edge; in young specimens there may be only 1 or 2 plates, or none at all. There are several plates in the second axil, usually arranged longitudinally, and occasionally one in the third, only separating the ray divisions by a narrow angle. Anal tube narrow, composed of elongate plates, bordered on either side by rather weak perisome which readily breaks down, so that rarely are more than two or three tube plates found intact in the best preserved specimens; margins of posterior rays facing tube rounded, and without sutural faces. Column large and long, composed near the calyx of extremely thin columnals, varying progressively from 4 to the millimeter in young specimens to 3 and 2.5 to the millimeter in mature (Pls. LVI, figs. 10, 8, 5; LVII, figs. 1, 2); these continue with slightly diminishing diameter for a short distance—2 mm. in young to about 15 mm. in mature—when the column suddenly and abruptly contracts 1 to 2 mm.; here somewhat longer columnals begin to be interpolated and continue until near the distal end. Some of these slightly project and their edges are studded with small cogs or teeth (Pl. LVI, figs. 5*b*, 6); in some specimens these denticulate columnals occur at regular intervals (Pl. LVII, fig. 2), while in others they are closely crowded together so that each columnal, or every other one, appears to be of this character (Pls. LVI, figs. 3*a*, *b*; LVII, fig. 1). The column near the distal end tapers to a fine, branched root, with a few very strong cirri in the lower part (Pl. LVI, fig. 3*b*): in young specimens it regularly tapers distally from the point of contraction. Column of a mature specimen about 480 mm. (20 inches); length of proximal enlarged part in mature specimen, 15 mm., in young, 2 mm.; diameter in mature specimen at top of enlargement, 8.5 mm.; at bottom, 7 mm.; below enlargement, 5 mm.; in a young specimen with enlarged part 2 mm. long the diameter at top of enlargement is 2.7 mm.; at bottom, 2 mm.; and below, 1.5 mm.

This is the widest known species, not only of *Taxocrinus* but of the entire Flexibilia group. Next to *Platycrinus hemisphericus* it is one of the most abundant species at the celebrated Lower Carboniferous locality of Crawfordsville, Indiana, and during the last fifty years has been distributed among the principal museums of the world. It is singular, therefore, that it should not have been described at an early day along with the other abundant crinoids of that locality, and that, although often mentioned and figured, it should remain for me at this late day to bring to light out of a mass of confusion and misunderstanding the name by which under the rules of nomenclature it must be known. The species is known in collections the world over under one of two names, viz., *Taxocrinus* (or *Forbesiocrinus*) *multibrachiatus*, and *Taxocrinus* (or *Forbesiocrinus*) *meeki*. In the early collections made by Worthen, Corey, Hovey, Bradley, Bassett, Braun and others, it was labelled *Forbesiocrinus meeki* upon the authority of Hall, whose species of that name was founded upon a very imperfect specimen without the arms preserved which was found in the lower part of the western Keokuk on the Mississippi River, and which moreover does not belong to *Taxocrinus*. That specific name accompanied the specimens of the Crawfordsville species into most of the European and many of the American collections. Good figures of a characteristic specimen of it were published by Quenstedt in 1885 (Handb. Petref., vol. 4, p. 946, taf. 75, figs. 24, 25) under *Forbesiocrinus;* and by Von Zittel in 1895 under *Taxocrinus* (Grundzüge Pal., p. 138, fig. 273).

In all collections and exchanges labeled by Wachsmuth the name *Taxocrinus multibrachiatus* Lyon and Casseday was applied to the fossil. The latter species, under the genus *Forbesiocrinus,* had been described by Lyon and Casseday along with some other well-known Crawfordsville species upon specimens said to be from Montgomery County, Indiana, and other localities, but without any published figures; as the description agreed in a general way, the present abundant form was supposed to be the one intended. By this means their name became established for the crinoid under consideration in the collection of the Museum of Comparative Zoology at Harvard; and in that of Wachsmuth and Springer. Now Lyon's species, *multibrachiatus,* as is clearly demonstrated by examination of his type specimen and by comparison with numerous other good specimens obtained in the same county, but from another locality and horizon, is an entirely different thing, having a solid anal side and being a true *Forbesiocrinus.* Hall's *F. meeki* also proves not to belong to this species or genus, but to *Parichthyocrinus.* Therefore those two species are eliminated from consideration in connection with this.

In 1880 Dr. White, sharing Wachsmuth's opinion of the identity of the common Crawfordsville form with Lyon's species, described and figured what he took to be a variety of it under the name *Taxocrinus multibrachiatus* var. *colletti.* He proposed his variety upon the supposed fact that it had 5 primary radials (R+4 IBr) in the anterior ray. This is not the case, as his own figure shows—drawn by some one who did not understand the specimen; the fourth plate is the axillary, as appears beyond a doubt by the shape of the plate which is angular above instead of having a concave waving suture line as all the non-axillary plates have. The type specimen, formerly in the collection of Professor John Collett of the Indiana Department of Geology, and supposed to have gone into the State Museum, cannot be located. But the figure, though carelessly drawn and plainly incorrect in some details, shows a thoroughly characteristic specimen of this species, a little more elongate than the average (Pl. LVI, fig. 1). The stem, with its abrupt change from the thin proximal columnals to some other structure not well shown and probably not properly exposed in the specimen by preparation, tells the story with absolute certainty; and the usual pustulose ornamentation is also present to reinforce the identification. So White really figured and described a perfectly normal specimen having the characteristic structure of the species, and it must therefore take his name in a full specific sense. But for this Quenstedt's figures, which are easily recognizable, would have taken the species under *T. meeki* Quenstedt (not Hall).

Miller and Gurley's *T. splendens* is founded upon an average specimen of the species, with the characteristic stem and pustulose surface, as can be readily seen by comparing the figures in Bulletin 8, Illinois State Museum, plate 5, figures 3, 4, with those on the two plates herein. The authors in the same volume, page 8, expressly recognized White's variety as a good species, but did not point out wherein their own differed from it, contenting themselves with their frequent conclusive declaration in such cases, that there is no described species for which it can be mistaken, "by anyone competent to make a comparison."

*Taxocrinus colletti* is a thoroughly well-marked species, standing between *T. ungula* and *T. praestans* and perfectly distinguished from both, in addition to other characteristics, by its remarkable stem. The peculiar and abrupt contraction, well illustrated by the figures, is not known in any other crinoid except the little known "*Taxocrinus*" *polydactylus* of the Irish Carboniferous, and it is constant for the species in both old and young. I have 60 specimens with this part of the stem attached, and there is among them not a single departure from the rule. The change is very sudden, not only in the diameter to the extent of about a millimeter, but also from uniformly thin to alternating columnals; the latter, however, is not always observable on account of the peculiar surface markings; the conical enlarged part is also markedly shorter than in any other species.

The roughened or closely studded surface of the stem below the contraction is unique, at least among the Paleozoic crinoids; as ordinarily found it looks like an irregular marking which was at first supposed to be the work of parasites, but careful cleaning of the specimens brought out a certain regular arrangement of peripheral beads into whorls, at various intervals, which suggested that the intervals between them might be the sockets for cirri. In the magnificent specimen shown by Plate LVI, figures 3*a, b,* the stem is complete and in place, though separated in the drawing for convenience; it shows the sculpturing very plainly for about three-fourths of its length, with the toothed whorls very close together but altogether too irregular for any connection with cirri; below this part the enlarged nodal columnals appear quite regular, and from several of them the stumps of strong single cirri are seen projecting, but with no indication of any others constituting a whorl. The structure is doubtless nothing more than a bead-like peripheral ornamentation of the columnals, such as are shown upon stems of *Millericrinus* (De Loriol, Crin. de la Suissee, pls. 12, 21. The stem of a maximum specimen is about 20 inches long, indicating a quiet, fairly deep-water habitat.

This species is a thoroughly characteristic example of the genus as I understand it, and by reason of the number of individuals and their excellent preservation lends itself especially well both to statistical examination of its general characters, and to the study of structural details. I have upwards of 200 specimens, nearly half of them free from the matrix, and with all or nearly all their rays intact. Upon these I have tabulated the data as to the number of brachials in the first and second divisions of the rays, with the following result:

In 93 specimens having 444 rays exposed, only 6 show any departure from the normal number of 3 primibrachs, these having less than 3 in 19 rays.; thus the generic character holds good for this strong species with a variation of less than five per cent. In the 887 rami showing the secundibrachs 516 have 3 IIBr, and 371 have 4 or more; while therefore the shorter habitus predominates, it is only to the extent of about 58 per cent of the whole; so that the species must be considered variable in this character. The increase of interbrachial plates with growth of the individual is shown by the series of specimens on Plate LVI. Some authors with sufficient literary energy would have made several species out of them on this character.

The preparations illustrated on Plate LVII show in the greatest detail the essential structures which characterize the genus, and to a greater or less degree the family:

(1) The *Posterior Basal.* We have this in almost every condition of exposure to bring out the special fact concerning it, that it is not suturally united to succeeding plates at its distal margin, but supports the anal tube in a rounded socket well down upon its outer, or dorsal, surface; figures 5 and 6*a* show it with the lower plates of the tube in place, the bordering perisome intact on the right side, and the left posterior ray removed. In 6*a* the remnants of the thin and fragile ventral perisome are seen, being as much of it as has ever been found in this species. In this specimen part of the right posterior ray is removed, and the inner side of it is shown at 6*b,* where the rounded lateral margins next to the anal side and above the interbrachials on the other side may be seen, with the slight linear depression marking the attachment of perisome; 6*c* is the left posterior ray of the same specimen, disarticulated at the basi-radial suture, and posed so as to show its left margin, with the sutural faces connecting with the interbrachials whose apposed faces are seen at the left of 6*a;* it also shows the inner surface of the ray. On the latter are seen fine longitudinal grooves starting on the secundibrachs, running with several of them parallel for some distance until in the distal part they are replaced by a good-sized median furrow, bordered by small depressions which form the seat of attachment of side or covering pieces. It looks as if these numerous longitudinal indentations on the IIBr, IIIBr, and partly on IVBr, served also for the attachment of perisome below the base of the free arms, perhaps covering some smaller ramifications of

the food-groove, or perhaps solely for support. The smooth and rounded right margin of the part of this ray below the axillary is shown in figure *6d;* the proximal articulating face of the radial in *6e;* and the distal face of the second primibrach above it at *6f.* These views of the articulating faces, together with those shown by figures *7a-h* from detached brachials in a similar specimen up to the axillary IIIBr, show the great depth and massiveness of the Taxocrinoid ray, as compared with that of *Forbesiocrinus.*

Returning to the posterior basal,—in figure 4 it is fully exposed free from the tube plates, showing the relatively low position of the socket, the strongly rounded distal margin connecting by an even curvature with the smooth margins of the posterior rays, and the complete absence of any face for sutural connection, either upon this plate or those to the right and left of it. All this is further emphasized by figures *8a, b,* where we have a well-preserved calyx entirely freed from the matrix dorsally and ventrally; *8b* shows the same view of the posterior basal, and the curved margins of the adjoining rays; and *8a* the inner edge of these margins connecting in a gentle curve with that of the posterior basal, all perfectly rounded and free from any sutural connection. These figures show that the posterior basal is sometimes really more symmetrical than it appears; the leaning of the tube to the right, or the apparently greater excavation of the right shoulder, being often partly the result of pressure in fossilization. Figures *8a, b* bring out clearly the next important point in typical *Taxocrinus,* viz.:

(2) The *Interbrachials.* These instead of running upward to an apex between the ray divisions have a more or less curved and crescentic distal margin marking the limit of solid, suturally connected plates, and the beginning of pliant perisome; the margin is smoothly rounded, and the perisome attached at its inner edge, as is finely shown in figure *3a.*

The various stages of the arcuate sutures between brachials, which gave rise to the notion of "patelloid plates," are thoroughly illustrated on the same plate; the ordinary form—broad median curvature of the exterior suture line—is seen in such specimens as figures 2, 3, 4, 5; the extreme form, where the projecting lips from the proximal faces look as if cut off by transverse lines into separate plates, in figure 1. Figure 9 shows that the external appearance depends purely on the condition of preservation of the surface, this being a weathered specimen in some parts of which the sinuous suture lines are plainly visible, while in others they have been obliterated by erosion, leaving the sutures as they actually are just below the surface, viz., straight lines. The detailed structure of this may be seen in figures *6a, b* and *7a, b,* in the latter of which the projecting lip, and the corresponding indentation fitting it on the plate below, are drawn from the separated plates; and the suture line, exteriorly arcuate on the face of $IBr_2$ in *6a,* is seen to be perfectly straight at the ventral side in *6b.*

Among the numerous specimens of this species some interesting special cases have been observed. Among these are—

(3) *Malformation.* This is shown by figures 10*a, b, c* of Plate LVII, where the specimen has apparently six rays, the left posterior radial being an axillary and supporting two equal series of primibrachs; there is accompanying confusion among the basals, only four of them being in the ring, while the fifth is superimposed at the posterior side, as shown in the diagram. Still more interesting than this is a remarkable case of—

(4) *Recuperation* (Pl. LVI, figs. 11*a, b, c*). In this case the entire crown except the infrabasals and one basal has been broken off and replaced by new growth; the stem and plates mentioned clearly belong to a much larger crinoid, and the one remaining basal tells very plainly what has happened. Here also are six rays, one directly following the old basal without any regard to its angular axillary face which remains exposed exteriorly; one opposite to it, and two each from axillary radials at either side; three greatly unequal new basals are developed beneath these. This individual had only one basal left to build upon, and the recuperation of the entire crown from this indicates that the seat of vitality was lodged low

down within the infrabasals. The structures can be well studied in the diagram, 11*c*, where the old plates are shaded and the new growth shown in outline.

Recuperation of more than a single ray in Paleozoic crinoids has not hitherto been recorded, but I am now able to report an interesting case of apparently habitual detachment of all the arms in life, and occasional regeneration, in the rather abundant species of the Cincinnati area described as *Heterocrinus juvenis* Hall (24th Report New York State Mus., 1872, pl. 5, figs. 9, 10; Meek in Palaeontology of Ohio, vol. 1, pl. 1, figs. 3*a*, *b*). The species is usually found in good preservation, except that by far the greater number of specimens are minus the arms, as shown in Hall's figures 9 and 10 and Meek's figure 3, above cited. The break is almost invariably at the level of the tegmen, just above the first primibrach, and it includes the anal tube as well as the arms. This loss of the normal food-gathering apparatus was not immediately fatal, for in a large number of individuals the fractures were partially repaired, leaving the surfaces smoothly rounded; and the stumps of rays are often bent inward as if trying to close over the tegmen, as shown in Hall's figures. Efforts at recuperation were made, sometimes producing a new set of arms, usually of a different size or color and more or less imperfect, and sometimes resulting only in the addition of a few dwarfed brachials.

This tendency to cast off the arms resulted in a remarkable dwarfing of the crown, which is usually no larger in diameter than the stem, while the latter, as compared with the stem of crinoids generally, appears relatively of enormous size. Among 195 specimens of this species in the collection before me 117 have lost their arms, leaving the fractured surfaces rounded, while 55 show more or less recuperation. Specimens with the arms in the normal condition, like Meek's figure 3*a*, are quite rare.

Similar occurrences are frequent among the Recent Bourgueticrinidae. Danielson[1] has described some of them in the Arctic species, *Bathycrinus* (*Ilycrinus*) *carpenteri*, and Doederlein[2] in species of *Bathycrinus* and *Rhizocrinus*. The species of these genera in which the loss and occasional regeneration of arms are chiefly observed all have the relatively very large stem and diminished crown seen in the fossil species above mentioned; and, as in that species, the separation of the arms seems to be a very common occurrence, leading to the suggestion by both these authors that it may have been a voluntary autotomy. Some of the instances of regeneration are very remarkable—one reported by Doederlein (Siboga, p. 6, pl. 5, fig. 3) being that of a stem which had lost the entire crown, but still had life enough to regenerate structures at the proximal end, which took the form not of calyx plates, but of radical cirri, thus producing the singular arrangement of a stem with a root at each end.

*Types.* The original of White's description cannot be found. The other specimens figured herein are in the author's collection.

*Horizon and locality.* Keokuk division of the Lower Carboniferous. Abundant at Crawfordsville, Indiana; a few specimens have been found at Indian Creek in the same county at a horizon a little lower than the beds at Crawfordsville. This is one of the very few species which is found in both the Crawfordsville and Indian Creek beds; it seems to have begun in the latter, where it is rare, and culminated in the former.

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[1] Norwegian North-Atlantic Expedition, 1892, pp. 10-12, pls. 1, 3.

[2] Gestielten Crinoiden der Siboga-Expedition, 1907, pp. 6-18, pls. 1-8; Deutsch Tiefsee-Expedition, 1912, pls. 3, 4, 5, 6.

### **Taxocrinus praestans** n. sp.

*Plate LVIII, figs. 1-8*

The largest *Taxocrinus* known, five adult specimens averaging 70 mm. high by 45 wide; base 13 mm. It is one-third to two-fifths larger than the largest specimen of *T. colletti,* which it resembles in general form and proportons, but from which it differs decisively in the stem; this, instead of diminishing in size all at once by a sudden constriction where the thin columnals end, tapers gradually to the minimum for a considerably greater distance, passing imperceptibly into longer and alternating ossicles. There is also no indication of any peripheral denticulate ornamentation, and the stem is preserved in three specimens for a sufficient distance to show that it has the ordinary form for the genus, like that of *T. ungula.* This distinction is confirmed by several minor differences. The brachials throughout are relatively narrower, and especially deeper; the interbrachial areas wider and the plates more numerous. The IIBr are almost uniformly 4 instead of 3; the five specimens are all free from the matrix, exposing 50 rami, of which 43 have 4 IIBr and 7 have 3; so that instead of a proportion of 58 per cent with 3 IIBr, we have here 86 per cent with the longer division. The basal plates have a peculiar shape; the apex is prolonged up between the radials like a narrow tongue, and the basi-radial sutures are sinuous, so that the proximal face of the radials is broadly curved instead of angular as usual; this may be seen in figures 1, 2, 3 of Plate LVIII, and is the case in another large specimen not figured; it is not so in figure 4, of a specimen from a different locality.

In none of the specimens is the anal side preserved intact, all being injured or distorted in that part; from what is left it is evident that the tube itself was not very strong, but was bordered by unusually strong perisome at the right side as in *T. ungula,* while at the left the perisome must have been weak, as no remnant of it is found next to the left posterior ray in any of the specimens. The interbrachial development is in accordance with the mature stage represented by the large specimens, and the broadly curved crescentic distal margin with perisome following is very conspicuous. Four of the specimens are from a single colony in the Indian Creek beds; they are remarkably uniform in size, the fourth being as large as the three which are figured, 1, 2, 3; the other one, figure 4, is from the closely equivalent beds in Washington County, Indiana. I have figured on the same plate with these several young specimens found in the same locality, some of them from the same colony; they may or may not belong to this species, not having the stem preserved to determine it except in figure 8, which has rather that of *T. colletti* but without any peripheral ornament. No intermediate stages of this species were found, and one need only compare figure 1 on Plate LVII, of a specimen from the same locality, with the four large figures on Plate LVIII, to see that there is no reason for thinking that the much smaller *T. colletti* is the younger stage.

*Types.* Author's collection.

*Horizon and locality.* Lower Carboniferous, Keokuk Group, below the Crawfordsville beds; Indian Creek, Montgomery County, and Canton, Washington County, Indiana.

### **Taxocrinus giddingei** (Hall)

*Plate LIX, figs. 1-12*

*Forbesiocrinus giddingei* Hall, Geology Iowa, I, pt. 2, 1858, p. 633, pl. 17, figs. 2, 4.—Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1865, p. 140.

*Taxocrinus giddingei,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 48.—Keyes, Geol. Surv. Missouri, 1894, p. 223.

*Forbesiocrinus elegantulus* Miller, Bull. 4, Geol. Surv. Missouri, 1891, p. 40, pl. 5, figs. 14, 15.

A very small species. Crown short and wide, broadly spreading below, widest about the axillary primibrach, where height to width is about 1.1 to 1. Calyx low, with broadly curving sides; spread from base, 1 to 3.2. Rays wide, convex, fairly prominent, tapering suddenly beyond the secundibrachs to relatively slender branches, and infolding shortly beyond third bifurcation. Sutures slightly sinuous, interbrachial areas wide, with numerous strong plates followed by perisome. Surface smooth. Dimensions of crown, average of specimens including the smallest and largest: height, 17 mm.; width, 15 mm.; base, 4.2 mm.

IBB low, resembling a thin columnal. BB small, acute-angled. RR the largest plates in the calyx. IBr 3, two and one-half times as wide as long, slightly tapering to the axillary which is a little wider; IIBr 3, almost as large as IBr; IIIBr 4, exceptionally 3 on the inner ramus, only half as large as IIBr and followed by slender arms; higher brachials wider than long. Anal area considerably wider than others; tube small, resting in socket at right upper corner of post. B, bordered by strong plates on either side, sometimes as large as the tube plates, and making post. B look as if angular above. Column large, with proximal enlargement composed of uniformly thin columnals followed by long and short ones alternating.

This is a remarkably constant species in size; in 30 specimens the variation lies between 15 mm. and 20 mm. in height, with scarcely any extremes beyond these. The secundibrachs are constant at 3 for all the specimens. The anal side is in a transition stage towards *Forbesiocrinus,* having in some specimens a considerable resemblance to that of *F. multibrachiatus.* The Taxocrinoid character of the species is well fixed, however, by the condition of the interbrachial areas with their well-defined crescentic distal margin (Pl. LIX, figs. 5, 8, etc.) followed by perisome (fig. 10). S. A. Miller's *Forbesiocrinus elegantulus* (Pl. LIX, fig. 11) is founded on an average specimen from the typical locality, where the species is fairly abundant in the upper beds. I have referred to it a form occurring sparsely in the Keokuk beds at Canton, Indiana, which ranges a little larger in size, and might prove different if we had better material for comparison.

*Types.* Hall's original is in the American Museum of Natural History, New York; Miller's in the University of Chicago; and the other specimens figured and studied are in the author's collection.

*Horizon and locality.* Lower Carboniferous, Warsaw Group and top of Keokuk; from the upper beds at Boonville, Missouri, and perhaps rarely in the somewhat lower Keokuk beds at Canton, Washington County, Indiana.

### **Taxocrinus shumardianus** (Hall)

*Plate LIX, figs. 13-16*

*Forbesiocrinus shumardianus* Hall, Geology Iowa, I, pt. 2, 1858, p. 671, pl. 17, fig. 1.—Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1865, p. 140.

*Taxocrinus shumardianus,* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 49.—Keyes, Geol. Surv. Missouri, IV, 1894, p. 224.—Springer, Jour. Geology, XIV, 1906, pl. 7, fig. 17.

A larger species than *T. giddingei;* similar to it in general aspect, form and proportions, but differing in the fact that the basals in the regular areas as well as in the anal are truncate and pass up between the radials to a sutural connection with the first interbrachial; they are therefore much more elongate. Also the anal tube is smaller, and is bordered by the usual weak perisome of the genus, instead of by strong plates at either side. The crown is usually a little higher than wide, the average dimensions of 6 mature specimens from the type locality being,—height of crown, 25 mm.; width at level of first IIIBr, 23 mm.; base, 5 mm.; calyx, 10 mm. high at IAx by 15 wide.

While some specimens of smaller size occur at St. Louis, the type locality, the usual habitus is like that of the type, figure 13; allowing for the smaller ones, the species averages decidedly larger than the closely related form from Huntsville. The largest of all is the beautifully preserved and very mature specimen shown in figures 14*a, b,* which was imbedded in a very fine-grained calcareous matrix, from which I was able to free it on both sides. It is the second *Taxocrinus* found preserving any recognizable portion of the tegmen. Here we have some indistinct remains of the integument composed of extremely fine plates, part of an ambulacrum, and the five orals lying near the center, but somewhat separated; all these have fallen down into the bottom of the calyx, and are therefore displaced.

This crinoid must have been in a very unusual state of perturbation at the time of its demise. Ordinarily the arms at death both in Recent and Fossil crinoids are found either flexed or extended uniformly; but in this case part are bent one way and part another, as may be readily seen by comparing the two figures, in drawing which the specimen was rotated sidewise so that left and right are reversed, the corresponding arms being lettered. In the anterior ray, two of the arms at *e* are seen in the dorsal view (fig. 14*a*) to be folded backward upon themselves, exposing their ventral side to the extremities, and those at *f* were so, but are broken off; the other view (fig. 14*b*) shows several arms (a', b', c', d', g', h') curved upon themselves in exactly the opposite way, the dorsal side of the distal extremities coming into view as they bend over toward the disk. An interesting thing in this specimen is the great thickness of the intersecundibrachs between the main divisions of the rays, which project upon the ventral side like short pegs, being in this respect entirely unlike those forming part of the calyx wall between the rays; the smaller plates between the IIIBr project in a similar way.

The number of IIBr seems to be fixed at 3, with occasionally one wanting. And the inner ramus of the IIIBr has almost uniformly only 3 plates, while in *T. giddingei* this is only occasional. The fact that the interbrachials pass down to the basals is very unusual, and constitutes an exceptional feature among the Flexibilia; it occurs sporadically in *Wachsmuthicrinus thiemei,* and occasionally in the next following species of the Kaskaskia; but nowhere else that I know of in this group.

*Types.* Hall's original is in the Worthen collection, University of Illinois. The other specimens figured and studied are in the author's collection.

*Horizon and locality.* Lower Carboniferous, St. Louis Group; St. Louis, Missouri, perhaps passing up to the Lower Kaskaskia in Monroe County, Illinois.

### **Taxocrinus huntsvillae** n. sp.

*Plate LIX, figs. 17-25*

A very small species of type similar to that of *T. shumardianus,* but differing in general proportions, the crown being rather wider than high, and in the form of the rays which instead of being broad and rounded are narrower and more elevated, sometimes tending to become angular. As usually found with arms folded the average dimensions of over 50 specimens are: height of crown, 13 mm.; width at level of first IIIBr, about 13.5 mm.; diameter of base, 3 mm.; spread of calyx to first axillary, 3 to 12.

This species occurs chiefly at a single locality near Huntsville, Alabama, where I have obtained it in large numbers and good condition; and it is from a higher horizon than *shumardianus,* being from the Ohara member of the Ste. Genevieve formation in the earlier Kaskaskia. While the differences upon which it is separated from that species are rather slight, they are strikingly constant. There is a remarkable uniformity in the small size, and the relatively lower and broader crown, while the tendency to angularity in the rays imparts a sharpness of aspect which makes the specimens readily distinguishable. Maximum specimens do not exceed about 15 mm. in width. The interbrachials usually touch the basals, but this character is not without exceptions, a few specimens being found in which the connection is wanting in one or more interrays. In the latter condition this form persisted sparingly into the higher Kaskaskia beds (Pl. LIX, figs. 23-25). The species is in fact an intermediate stage in a little line of retrogression which marked the concluding phases of the genus in the last three members of the Carboniferous—depauperate species of the short type, in which the arms were growing shorter: In *T. giddingei* of the Warsaw, with 3 IIBr like the antecedent *T. ungula,* the third arm division also began occasionally to have 3 plates; in *T. shumardianus* of the St. Louis this character became constant for the inner ramus and continued to the Lower Kaskaskia in the present species; in *T. whitfieldi* of the higher Kaskaskia the IIBr were reduced to 2, and sometimes also the IIIBr, with an occasional reduction in IBr; and there the genus ended so far as known.

In the figures of these four species there is a frequent appearance of straightness in the sutures between brachials which must not be taken as representing the actual facts; nearly all these specimens have been more or less weathered, and the patelloid projections being very thin, as in the somewhat similar *T. intermedius,* they have largely disappeared; careful examination with a magnifier discloses clear traces of them in nearly every specimen, but this is not easily shown in the drawings.

*Types.* Author's collection.

*Horizon and locality.* Lower Carboniferous, lower part of Kaskaskia Group; it occurs chiefly in the *Platycrinus* bed of the Ohara limestone, equivalent to part of the Sté Genevieve formation, but also passes up into the overlying beds equivalent to the Renault. Huntsville, Alabama.

### **Taxocrinus whitfieldi** (Hall)

*Plate LX, figs. 1-11*

*Forbesiocrinus whitfieldi* Hall, Geology Iowa, I, pt. 2, 1858, pp. 632, 633, fig. 104.—Hall, Supplement Geology Iowa, 1860, p. 88.—Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1865, p. 140; Geol. Surv. Illinois, II, 1866, p. 243.

*Onychocrinus whitfieldi,* Meek and Worthen, Geol. Surv. Illinois, V, p. 552, pl. 20, fig. 3.

*Taxocrinus whitfieldi,* Wachsmuth and Springer, Revision Palaeocrinoidea, I, 1879, p. 49.

*Forbesiocrinus cestriensis* Hall, Supplement Geology Iowa, 1860, p. 68.

*Forbesiocrinus parvus* Wetherby, Jour. Cincinnati Soc. Nat. Hist., 1879, p. 138, pl. 11, figs. 4*a, b* (Separate p. 5).

*Taxocrinus wetherbyi* Miller and Gurley, Bull. 6, Illinois St. Mus. Nat. Hist., 1895, p. 41, pl. 4, figs. 3-5.

The last known survivor of *Taxocrinus.*

A medium-sized species. Crown low and broad, much wider than high, infolding about the lower IVBr, and expanding with a broad curve to that level, where height to width is about 1 to 2 in mature specimens, somewhat less in the young. Calyx a continuous wall to the level of upper IIBr except at the anal side, with rays but little prominent and iBr areas little depressed; height to width at IAx, 1 to 3.5; spread from base, 1 to 4. Side outline low convex. Rays bifurcating about four times, the last one after infolding; diminishing greatly at third division; free arms small and delicate; sutures moderately sinuous. iBr areas wide, plates numerous and strong to level of second axillary and followed by perisome. Surface smooth. Dimensions of crown in maximum specimen: 17 mm. high; 35 wide; base, 6; in a small one, 7.5 mm. high; 10 wide; base, 2.2 mm. Average adult specimens about 12 mm. high by 24 wide.

IBB visible as low pentagons. BB large, sometimes connecting with iBr in one or more rays. RR and IBr of about the same width. IBr 3; IIBr 2, fully incorporated in calyx wall, two-thirds as wide as IBr; IIIBr 2 or 3 in inner ramus, 3 or 4 in outer; higher divisions very narrow. iBr plates very large for three ranges of about equal size, a fourth one smaller followed by perisome; areas nearly flush with rays to height of IIBr 2, where they curve inward. Column large, with long conical enlargement of very thin plates next to calyx, below that cylindrical with alternating columnals.

This species is the conclusion of the line of retrogression which marks the extinction of the genus in the latest member of the Lower Carboniferous. It has several peculiar features: The interbrachial structure in the regular areas is the strongest found in any species of the Taxocrinidae, and this is correlated with an absolutely weak anal side, containing nothing but perisome bordering the small tube; of such strong bordering plates as are seen in *T. giddingei* there is not a trace. It has the lowest and broadest crown of any species; its habitus is that of a very broad, shallow basin (figs. 3*a*, 4) with arms folding over the rim as in figure 3*c;* wherever the specimens are preserved in a soft matrix they retain the form shown in figures 1-4. I have 6 such specimens, and there is little variation in their form and proportions; specimens like figures 5, 7, 9, 11 are laterally compressed, and give an erroneous idea of the natural contour.

This extreme shortening of the crown is accompanied by a corresponding reduction in the number of brachials; 2 IIBr is the rule throughout upwards of 30 specimens, with only two exceptions; in the majority of cases the inner ramus of the IIIBr has only 2 (figs. 5, 6), never more than 3, and the outer not more than 4. No preceding species has shown any such shortness in the arm divisions. There is also a tendency to reduction in the number of IBr. I have found this in some rays of four specimens. The separation of the radials by upward prolongation of basals, begun in *T. shumardianus,* is continued to some extent, but quite irregularly, in this species.

*T. whitfieldi* is an exceedingly well-marked species, readily identified from fragments, and it occurs over a wide field, having been collected in Illinois and in several counties in Kentucky. Hall's type specimen is perfectly characteristic, and although not figured by him he gave a good diagram from which it would be readily recognized; nevertheless several synonyms have sprung up which have to be suppressed, including one by himself. Hall in the original description stated the horizon as Keokuk, and afterward in the Iowa supplement corrected this to read, Warsaw. Neither is correct, as was pointed out in 1873 by Meek and Worthen, who figured and redescribed the type, and gave the locality and horizon as opposite Kaskaskia, Randolph County, Illinois, in the Chester (Kaskaskia) division of the Lower Carboniferous, on the authority of Professor Worthen, who collected it.[1] Those authors (Geol. Illinois, vol. 5, p. 553) pointed out very clearly the difference between this species and *Forbesiocrinus wortheni,* and for the reasons there stated referred it to *Onychocrinus.* While this reference under our present conception of the latter genus cannot stand, the reasons given by Meek and Worthen are entirely valid to establish its place under *Taxocrinus,* as distinguished from *Forbesiocrinus* as then understood by American authors.

Hall described his *Forbesiocrinus cestriensis* from a well-defined specimen of this species from the Kaskaskia at Chester, Illinois, without any figure; this I have now supplied for comparison from the type in the Worthen collection (fig. 11). Miller and Gurley's figure of their *Taxocrinus wetherbyi* needs only to be compared with that of the type of *T. whitfieldi,* figured long before their date by Meek and Worthen, and refigured herein (Pl. LX, fig. 1), to show the complete identity of the two. Nevertheless they applied their stereotyped formula, and said: "the species is so different from all others that no comparison with any of them is necessary to distinguish it." Wetherby's *Forbesiocrinus parvus* is only a very young, and therefore more elongate, specimen of this species, like figures 10*a, b.* His type specimen cannot be identified, but it is one of several small specimens which cannot be distinguished from mine, and is from the same colony at Sloan's Valley, Pulaski County, Kentucky, that produced numerous well-preserved specimens such as are shown by my figures 2, 3, 4, 5, 8, 10. His figures, enlarged two diameters, are undoubtedly incorrect in representing the interbrachials as continuing to an apex between the arms—a structure which might easily be misunderstood in small, dark-colored specimens like these.

*Types.* Hall's original is in the Worthen collection, University of Illinois, also the type of his *F. cestriensis;* that of Miller and Gurley's *T. wetherbyi,* and specimens used by Wetherby, are in the Walker Museum, University of Chicago; the others studied and figured herein are in the author's collection.

*Horizon and locality.* Close of Lower Carboniferous; Okaw formation, upper part of Kaskaskia Group. Randolph and Pope counties, Illinois, and Breckinridge, Grayson and Pulaski counties, Kentucky.

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[1] This is confirmed by my own collections from Randolph County.

## **PARICHTHYOCRINUS** Springer

*Plates LXI, LXII, LXIII*

*Parichthyocrinus* Springer, Amer. Geologist, XXX, 1902, p. 96; Jour. Geology, XIV, 1906, pp. 500, 519.—Zittel-Eastman, Textbook Paleontology, 1913, p. 206.

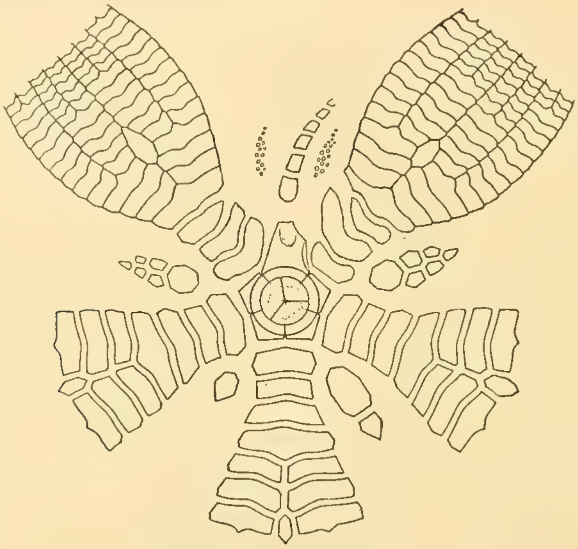

FIG. 50. *Parichthyocrinus*

Taxocrinidae with rays closely abutting above interbrachials. Crown ovoid. Infrabasals prone like a columnal, but not within the ring of basals. Posterior basal elongate. Radianal, if present, only in upper oblique position. Right, and sometimes left, posterior radial smaller than others. Interbrachials few. Primibrachs three. Arms dichotomous, interlocking. Column enlarging beneath calyx.

*Genotype. Ichthyocrinus nobilis* Wachsmuth and Springer.

*Distribution.* Middle part of Lower Carboniferous, Burlington to Keokuk; not known outside of the United States.

With its closely abutting and interlocking arms this genus does not fit very well among the Taxocrinidae, but would appear superficially to be more at home in one of the other families. It might be defined as a *Euryocrinus* with Taxocrinoid anal side, but the latter feature is so strongly marked that the genus must remain as I have placed it; and furthermore, the infrabasals do not have the characteristic position within the basal ring which holds *Euryocrinus* within its family. The infrabasals are very small, it is true, and rarely seen from the exterior, but they have the form and location of a thin top columnal, as shown by figure 4 of Plate LXIII; in one species they are nearly equal in size, and the small plate is usually in the anterior position.

Still closer is the resemblance of this form to certain species of *Forbesiocrinus* of the same stratigraphic position, having the same type of base, and in which the arms often abut somewhat closely above the iBr areas. In specimens of *F. wortheni* and *F. multibrachiatus* having a tendency toward modification of the anal side in the direction of a definite median series, some perplexingly close transitions may be found. Questions arising in regard to these can usually be settled by taking into account the decidedly restricted number of interbrachials in *Parichthyocrinus,* and the close arching of the lower brachials over them, and also a peculiarity of the right posterior radial, which in all the species, and in some the left posterior also, is much smaller than the radials of the anterior and lateral rays; it is crowded by excessive growth of the posterior basal until it has much the form of the primitive radianal in some of the Silurian genera. This is not the case in *Forbesiocrinus,* where that radial is of full size and is usually larger than the succeeding primibrachs; it will also usually be found that the larger basals in *Forbesiocrinus* will determine the matter.

A characteristic of this genus is the strong construction of its calyx walls and brachials, producing with the closely folded arms a firm, rotund body, which retained its form under pressure in fossilizing better than any others in this family; in this respect also it is more like the Ichthyocrinidae and *Forbesiocrinus.* This may be seen in the cross-sections of various plates shown on Plate LXI; although all very short, they begin to have great depth in the primary brachial series, and at the height of the tertibrachs they are at least three times as deep as they are long. These characters very naturally led to the reference of the first discovered species to *Ichthyocrinus*—the structure of the anal side, which would have precluded such a course, not being disclosed by the specimens then at hand.

Four species from two different horizons confirm the proposal made in 1902 for a separate genus for this form. Its stratigraphic range is not large, the genus being confined to the middle of the Lower Carboniferous, that is, so far as known, to the Upper Burlington and Keokuk groups.

The discrimination of species is necessarily made upon characters of a low order of value, aided by their stratigraphic position. The original descriptions, as is the case in many other genera, afford little assistance, being chiefly confined to statements of characters now held to be of generic or family rank, and of individual peculiarities in the specimens. The species may be conveniently arranged as follows:

### THE SPECIES OF PARICHTHYOCRINUS

I. Anal tube bordered by weak perisome.
  - Rays not prominent; arms broad and flat.
    - iBr few, in 2 or 3 ranges, mostly in vertical succession.
      - Crown higher than wide........................................*P. nobilis.*
  - Rays prominent; arms rounded.
    - iBr few, mostly large plates in succession for 2 ranges, followed by small ones at apex.
      - Crown wider than high........................................*P. meeki.*
    - iBr doubling in second range, making wider areas of 3 to 4 large plates.
      - Crown higher than wide....................................*P. subovatus.*

II. Anal tube bordered by strong plates,—transition toward *Forbesiocrinus.*
  - Rays not prominent; arms broad and flat.
    - iBr numerous in several ranges.........................*P. crawfordsvillensis*

## **Parichthyocrinus nobilis** (Wachsmuth and Springer)

*Plate LXI, figs. 1-16*

*Ichthyocrinus nobilis* Wachsmuth and Springer, Proc. Acad. Nat. Sci. Philadelphia, 1878, p. 254 (Separate, pl. 2, fig. 7); Revision Palaeocrinoidea, pt. 1, 1879, p. 35.

*Parichthyocrinus nobilis,* Springer, Amer. Geologist, XXX, 1902, p. 96; Jour. Geology, XIV, 1906, p. 522, pl. 6, fig. 17.

Type of the genus.

A large species. Crown low and broad, about as high as wide, rotund, broadly curving from base to infolding arms; widest about the lower IVBr, where height to width is about 1 to 1. Calyx a shallow basin, height to width at IAx, 1 to 4, spreading from base about 1 to 4. Rays and arms broad and flat, flush with the general curvature, infolding about the fourth bifurcation; sutures arcuate. iBr few, areas narrow and elongate, and but slightly depressed. Surface smooth or finely granular. Dimensions of crown in adult specimen: height, 38 mm.; width, 3.5 mm.; base, 6 mm.

IBB covered by column, but not within the ring of BB. BB low, visible as small triangles beyond the column, except post. B which is very large and wide, encroaching on r. post. R. RR and IBr short and wide, about as 1 to 3, increasing in width upward; r. post. R smaller than those of other rays. IIBr 3 and 4, of about the same size and proportions as IBr, and like them increasing in width upward; IIIBr 4 or 5 on inner ramus and 7 or 8 on outer, increasing slightly in width upward. Thus the whole ray widens regularly up to the lower IVBr, where the greatest expansion of the crown occurs; there is usually one more bifurcation, and all higher brachials are very short and wide. iBr consisting of a few large plates, in adult specimens either 1 large followed by 1 or 2 small ones in the apex, or 2 or 3 large in succession; or in very mature specimens 2 plates in the second range; in young none at all; the iBr area does not widen upward, but has about its maximum width in the first range. Anal tube very small and delicate, composed of elongate plates bordered by diminutive plates at the right and broken down perisome at the left. Column of moderate size, tapering gradually for a short distance, passing from very thin and equal to alternating columnals, and continuing smooth and cylindrical.

This species was founded upon the large specimen shown in figures 1*a, b,* described without illustration in the regular edition of the Philadelphia Academy Proceedings, but accompanied by a reduced photograph on a plate circulated with the separate copies of the paper. It was defective in the base and anal side, and from the resemblance of the closely abutting and interlocking arms to those of *Ichthyocrinus,* the anal side was supposed to be solid. The specimen was unique, and it was not until years afterward that the fine series now in hand were found, illustrating the species and genus in all its phases from the young to very mature. In 1906 I published a figure showing the structure of the anal side as now understood, to further demonstrate the necessity of a new genus for this form (fig. 10*b*);

this is now reinforced by three other good specimens showing the delicate, rounded anal tube, without any solid connection with the broadly rounded rays adjoining it (figs. 11, 12, 14).

An important thing brought out by the new material is the exact nature and function of interbrachial plates, which serve to fill up spaces between the brachial elements as required by the growth of the viscera. They begin to form at the suture lines on the inner surface of the calyx wall, and gradually force their way outward like wedges; thus the exterior surface of those plates which extend through is much less than the interior, and some never reach the outer surface at all. All this is beautifully illustrated by the preparations figured on Plate LXI; figures 1*c*, *d* show the opposite surfaces of the interbrachials in part of an interradius (numbered 1, 2, at the right lower corner of fig. 1*b*), together with the adjoining brachials; of the seven plates plainly visible at the inner surface only two and a mere point of a third have succeeded in reaching the exterior, and probably no more would have done so, as this is a very mature specimen, having doubtless reached its full size; the other four remained simply as wedges, just as the one at the left side of no. 1 appears in the end view, figure 1*d*. The relations of the plates are still better shown by figures 3*a*, *b*, *c*, *d*, from a detached part of the same specimen, in which the numbers and lettering on the different plates sufficiently explain them, if it is added that the part of the ray at the right is displaced, and stands somewhat lower than it would in its natural order. In the middle interradius 6 large plates at the interior are represented by only 4 much smaller ones at the exterior, while those that started and formed good-sized wedges in the second axil did not get through at all; their mode of growth, and the corresponding opposite sloping of the brachials, may be seen in figure 3*c*.

In this species 4 is about the maximum number of iBr that appear externally, and in younger specimens the number is progressively less, until none whatever are seen (fig. 16). Hence as a specific character this is about the weakest, and only of service if we deal in general averages; if merely based on definite numbers it is wholly worthless. In this species the peculiarity of the interbrachials is not simply the small number, but that the areas attain almost their full width at once—not increasing much above the first range.

The preparation also brings out some very peculiar modifications in the shape of the primary brachials due to the proximity of the anal structures. Figures 2*a*, *b* show the first 5 plates in the left posterior ray; the radial, which is very short exteriorly (fig. 2*a*, no. 1), is enormously produced inward at the right margin next to the anal area, and enlarged at the interior until it occupies about half the area of the whole five plates (fig. 2*b*); plates 2 and 4 on the other hand are greatly reduced, and 3, a good-sized plate exteriorly, does not reach the inside but remains a mere wedge, as shown in figure 2*d*. It is probable that similar distortions of the plates exist in the right posterior ray, as the radial on that side is always much smaller than the radials in the other rays (figs. 11, 12, 14). This feature seems to exist throughout the genus.

Another peculiarity is that in the posterior rays one of the primibrachs is much smaller than the others, narrowing toward the anal area to a knife edge, and sometimes not reaching it at all (fig. 14). This is due to the great curvature of the rays at this point.

The secundibrachs are inconstant, varying from 3 to 4 in about equal numbers throughout 16 specimens.

This species has only been found high up in the Upper Burlington limestone, near or in the transition beds toward the Keokuk; most of the specimens studied were found in a single colony.

*Types.* Author's collection.

*Horizon and locality.* Lower Carboniferous, upper part of Upper Burlington limestone; Burlington, Iowa.

### **Parichthyocrinus meeki** (Hall)

*Plate LXII, figs. 1-3*

*Forbesiocrinus meeki* Hall, Geology Iowa, I, pt. 2, 1858, p. 631, pl. 17, fig. 3.

*Onychocrinus meeki,* Meek and Worthen, Geol. Surv. Illinois, II, 1866, p. 243.

*Taxocrinus meeki,* Wachsmuth and Springer, Revision Palaeocrinoidea, I, 1879, p. 49.

Not *Forbesiocrinus meeki,* Quenstedt, Handbuch Petrefaktenkunde, 1885, pl. 75, figs. 24, 25 (= *Taxocrinus colletti* White).

Not *Taxocrinus meeki,* Von Zittel, Grundzüge Palaeontologie, 1895, p. 138, fig. 273; Zittel-Eastman, Text-book Palaeontology, 1896, p. 164, fig. 273 (= *Taxocrinus colletti* White).

A very large species. Generally similar to *P. nobilis,* except that the crown is relatively shorter and wider, the average of height to width of four specimens being 1 to 1.1, and the rays and arms are more prominent and convex, and the regular basals seem smaller, being scarcely visible beyond the column; also the column is more uniform, with non-alternating columnals. Calyx spreading almost horizontally, like a low saucer; height to width, 1 to 5; spread from column to IAx, 1 to 3; dimensions of mature specimen: crown, height 43 mm.; width 50 mm.; base at column facet, 11 mm.

This species occurs at the base of the Keokuk limestone. Four good specimens have come into my hands supplementary to the type. Three of these, including the two fine specimens figured, were found by the late Lisbon A. Cox at a single locality a few miles north of Keokuk, in a limestone intercalated between chert bands, which he considered to be really at the top of the transition bed, just underlying the true Keokuk; the fourth was found in exactly the same horizon at the upper end of the exposure at Nauvoo. It therefore occupies a definite horizon entirely distinct from those of the other species. It is readily distinguished from *P. nobilis* by the convexity of the rays and their divisions, which gives it a notably different habitus. The calyx is extremely low, almost horizontal; the unrivaled specimen shown in figures *2a, b*—one of the finest crinoids ever found in the Keokuk limestone—shows substantially the natural contour of the crown, being only a little compressed laterally; and the same very low calyx appears in all the other specimens. The IBB are always, and BB mostly, covered by the column, except post. B. The distribution of iBr is very similar to that in *P. nobilis:* two or three large plates in succession, or the second and third ranges broken up into smaller plates not materially increasing the width of the area. The 3 IIBr seem to be almost constant. The left posterior radial is usually reduced in size, as well as the right.

There has been much confusion in the literature regarding this species, partly due to its poor illustration. Hall's figure gave little idea of the anal side, which I have made clear by additional preparation (fig. 1). Comparison of this figure with those of other specimens leaves not the least doubt of their identity; Meek, who had the type before him, saw that it did not belong to *Forbesiocrinus* (Geol. Illinois, vol. 2, p. 243), and correctly pointed out the generic distinction that must be based upon the anal structure, referring it upon that ground to *Onychocrinus.* The "five other individuals of this species" mentioned in the above discussion were specimens of the common Crawfordsville *Taxocrinus,* labeled *meeki* in Professor Worthen's collection. This misidentification was made by Hall when describing some crinoids from that locality for his paper in 1861; it was accepted by the collectors, and thus the name as attached to an entirely different fossil was distributed by their labels among many museums of the world. Then Quenstedt and Von Zittel published figures of good specimens of the Crawfordsville species under this name, so that the erroneous reference became currently established in the literature; this will now have to be corrected by those interested, and all such specimens should be labelled *Taxocrinus colletti* as explained under that species.

This species is exceedingly rare, not having been found except at the horizon and in the vicinity mentioned above.

*Type.* Worthen collection, University of Illinois. The other specimens herein figured are in the author's collection.

*Horizon and locality.* Lower Carboniferous, base of Keokuk limestone; Nashville, Iowa, and Nauvoo, Illinois.

### **Parichthyocrinus subovatus** (Miller and Gurley)

*Plates XXI, fig. 6; LXII, figs. 4-17; LXIII, figs. 1-4*

*Taxocrinus subovatus* Miller and Gurley, 16th Rep. State Geologist Indiana, 1890, p. 347, pl. 5, fig. 3.

A medium sized species, very similar to *P. meeki;* differing mainly in its generally more elongate crown, and more lozenge-shaped interbrachial areas; it is also apparently smaller, as out of 40 specimens the largest is 34 mm. high by 30 mm. wide, and few attain a size of 30 by 25 mm. The average of six representative adult specimens gives the following proportions: height to width of crown at upper IIIBr, 1.1 to 1; of calyx at IAx, 1 to 3.5; spread of calyx from column facet, 1 to 3; so the crown is not so wide as that of *P. meeki,* and the calyx is higher and not so nearly horizontal below.

These characters of course have the minimum diagnostic value, and seem to be only of importance because they occur quite uniformly in a large number of specimens which are derived from a different horizon, viz., the upper part of the Keokuk limestone. If one of these specimens were found at the Iowa locality and horizon we should scarcely think of separating it from *meeki.* The difference in the interbrachials seems marked by a tendency to double the large plate in the second range, with another large one following in the third, thus making the areas more broadly oval. There is also a slight difference in the column in the rather greater contrast of alternating columnals in this species, although in both they take on great uniformity in the lower half of the stem. We have the stem complete in the two beautiful specimens figured on Plate LXIII, figures 1, 2, both of which show traces of irregular cirri for a considerable distance from the distal end; the stem tapers to a fine point without branching roots, and in a medium sized specimen is about 8 inches long. The IIBr are fairly constant at 3, a tabulation of the facts in 15 good specimens showing that number in 75 per cent of the rami, and 4 in the others. Right and left posterior radials are usually both reduced in size.

The fine series of specimens studied were found in two colonies at the Indian Creek, Indiana, beds, but the type and a few others came from the equivalent horizon in Washington County. This is one of the species which may be thought over-illustrated, resulting from the repeated accession of better material as the drawings were in progress, the two complete specimens having been obtained twenty years after the first discoveries at the locality. I have illustrated along with them a specimen with a solid anal series in the lower part, occurring in the large colony of specimens otherwise like it, which if found isolated might readily pass for *Euryocrinus* (Pl. LXIII, figs. 3*a, b*) ; I consider this only a sporadic occurrence; and in fact a close examination of the anal series shows traces of its Taxocrinoid affiliation in the presence of small plates at either side and an open space at the top (fig. 3*c*). There are one or two others with plates in similar condition.

The specimens figured on Plate LXII show a gradation from four large interbrachials in the adult down to one in the young; the type is an intermediate specimen with two, and was so described by the authors.

*Types.* Miller and Gurley's original is in the Walker Museum, University of Chicago. The other specimens figured are in the author's collection.

*Horizon and locality.* Lower Carboniferous, upper part of Keokuk Group, about equivalent to the Geode bed; Indian Creek, Montgomery County, and Canton, Washington County, Indiana.

### **Parichthyocrinus crawfordsvillensis** (Miller and Gurley)

*Plate LXIII, figs. 5-6*

*Taxocrinus crawfordsvillensis* Miller and Gurley, Bull. 3, Illinois St. Mus. Nat. Hist., 1894, p. 49, pl. 4, fig. 3.

A very large species. Crown higher than wide, about 1.2 to 1. Calyx greatly rounded, height to width at IAx about 1 to 2, evenly curved below. Rays not very prominent, arms broad and flat, bifurcating four times; sutures arcuate. iBr numerous, in several ranges of rather small plates; iIIBr present. Anal plates in a median series bordered on each side with numerous strong irregular plates. BB fairly large, visible as triangles or pentagons beyond column. iBr numerous, in large elongate areas. Surface smooth. Column large, with conical taper of very thin columnals next to calyx, passing into crenulated alternate ossicles which become uniform in lower half and increase in length downward; irregular cirri toward the distal end, which evidently terminated in a fine point without any branching. Crown in type specimen, 50 mm. high by 40 mm. wide; base, 11 mm.

This species from the Crawfordsville, Indiana, beds at a higher horizon than the preceding, represents a modification toward a solid anal structure similar to what is observed in species of *Taxocrinus* like *T. ungula* and *T. giddingei;* there is a median tube-like series, but it is bordered by plates much stronger than ordinary perisome; those adjoining the rays are nearly as large as regular interbrachials, but those next to the tube are smaller and more irregular. The only specimen we have showing the posterior side is crushed, and the arrangement of these parts disturbed. The authors in describing the species compared it with *Forbesiocrinus multibrachiatus* of Lyon and Casseday, from which they had difficulty in distinguishing it, but did so on the ground of the anal structure as follows (*op. cit.,* 51):

> In our species the azygous area is larger than the regular interradial areas, and has a series of five long longitudinally convex plates in the middle of the area, resting upon the truncated upper side of a basal plate, and extending as high as the third secondary radial; and on each side of this ridge of plates there are several smaller polygonal plates, and others extending beyond.

The similarity to *F. multibrachiatus* is still stronger when we consider the specimens of that species such as I have illustrated on Plate XXVIII, where there is a tendency to differentiation of the median plates of the anal area in form of a tube; and the presence of numerous ranges of interbrachials—far more than observed in any other species of *Parichthyocrinus*—must be also considered. It is a doubtful question, but I have been led to retain the species here by reason of the decided flatness of the arms, and the fact that *F. multibrachiatus* does not otherwise occur in the Crawfordsville beds but at a different horizon in the same formation, and also because the recent acquisition of a second specimen from the same beds confirms the general habitus. It is exceedingly rare, these being the only specimens found among the many extensive collections made at that famous locality during over fifty years.

*Types.* Miller and Gurley's original is in the Walker Museum, University of Chicago; that of figure 6 in the author's collection.

*Horizon and locality.* Lower Carboniferous, upper part of Keokuk group, above the Indian Creek horizon; Crawfordsville, Indiana.

## **ONYCHOCRINUS** Lyon and Casseday

*Plates LXIV-LXXIV, LXXV, figs. 14, 15; text-fig. 8*

*Onychocrinus* Lyon and Casseday, Amer. Jour. Sci., (2) XXIX, 1860, p. 77.—Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1865, p. 140, footnote; *ibid.*, 1866, p. 255; Geol. Surv. Illinois, II, 1866, p. 242.—Wachsmuth, Amer. Jour. Sci., (3) XIV, 1877, p. 185; Ann. and Mag. Nat. Hist., (5) I, 1878, p. 457.—Von Zittel, Handbuch Palaeontologie, I, 1879, p. 353; Grundzüge Palaeontologie, 1895, p. 138.—Wachsmuth and Springer, Revision Palaeocrinoidea, I, 1879, p. 53; *ibid.*, pt. 3, 1886, p. 145; Proc. Acad. Nat. Sci. Philadelphia, 1888, pp. 344, 353; *ibid.*, 1890, pp. 353, etc.—Miller, N. A. Geol. and Palaeontology, 1889, p. 264.—Zittel-Eastman, Textbook Paleontology, 1896, p. 163, 2d Ed., 1913, p. 206.—Jaekel, Zeitschr. d. deutsch. geol. Gesell., for 1897 [1898], p. 46.—Bather, Rep. Brit. Assoc. for 1898 (1899), p. 923; Treatise on Zoology (Lankester), pt. 3, 1900, p. 190.—Springer, Amer. Geologist, XXX, 1902, p. 95; Jour. Geology, XIV, 1906, p. 519.

*Oligocrinus* Springer, Amer. Geologist, XXX, 1902, p. 95; Jour. Geology, XIV, 1906, p. 519.

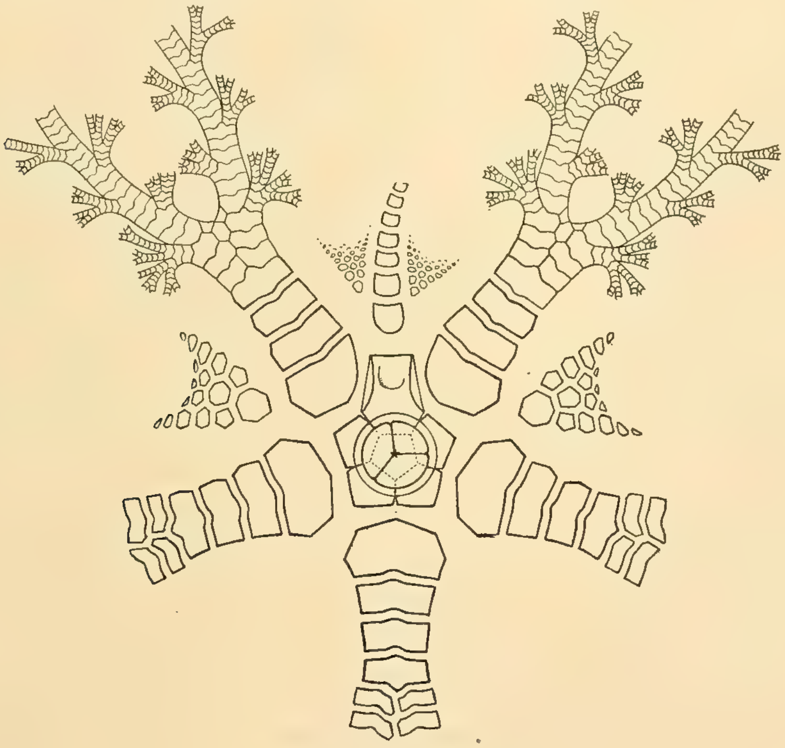

FIG. 51. *Onychocrinus*

Taxocrinidae with rays more or less widely separated above interbrachials. Infrabasals low, usually exposed beyond the column. Posterior basal elongate. Radianal, if present, only in upper oblique position. Interbrachials variable, few to very numerous. Primibrachs three or more. Arms heterotomous, in ten main trunks bearing ramules. Column enlarging next to calyx.

*Genotype. Onychocrinus exsculptus* Lyon and Casseday.

*Distribution.* Lower Carboniferous, Lower Burlington and equivalents to Kaskaskia; the United States and Great Britain.

*Onychocrinus* is the first genus among the Taxocrinoidea in which the true heterotomous arm structure became thoroughly developed. Its characteristic feature, giving to its typical forms a habitus wholly distinct from that of any other genus of the Flexibilia, is the division of the ray into two free trunks or rami, on which the arms are borne as subordinate, branching ramules, along with the extension of the main ray by the lateral union and interlocking of one or more pairs of secundibrachs, so reduced in size that the two together prolong the ray for some distance above the axillary at about the same size as below. The extent of this union is a matter of age in the individual; in young specimens the interlocking of the secundibrachs has not begun, while in the mature forms of some species it extends to five pairs of brachials. The genus is a direct development from *Taxocrinus* (analogous to that of *Barycrinus* from *Cyathocrinus*), having the anal characteristics of that genus carried to the extreme; and with a very young specimen it is difficult to distinguish between the two genera unless enough of the first ray division is visible to show whether it forks again by equal bifurcation; if not, it cannot be *Taxocrinus*.

Along with this character is a tendency to increase in the number of primibrachs, which in certain species gives an added length to the already long, free rays, and as said by Meek and Worthen (Geol. Surv. Illinois, vol. 2, p. 243) "imparts a peculiar physiognomy to the whole fossil quite obvious even to the most careless observer." These authors, at the place cited, gave a most excellent discussion of the characters of the genus, and especially pointed out that along with its free rays, it has the anal tube of the typical *Taxocrinus*. In the extreme species, where the arms are borne in small clusters near the extremity of the free rays, there is also a strong tendency for the whole crown to assume an extended position, with the rays projecting horizontally from a rather small central disk, suggesting to those authors comparison with a starfish or an Ophiuran, especially with the existing genus *Astrophyton*. This resemblance had led Lyon and Casseday, the authors of the genus, to the opinion that it forms a connecting link between the Crinoidea and Asteroidea; a view which Meek and Worthen, in the discussion above cited, showed to be without good foundation—"the resemblance being merely simulative, and not due to any close analogy of structure."

The greatest increase in the number of primibrachs is seen in one of the British species, *O. polydactylus*, in which they amount to 6 or 7. The first American species has only 3, after which follows a strong line of species with 4, being all of the extreme form; then the structure returns to the original 3, with which the genus ends. These differences are not irregular, but hold good for the species in America with few exceptions.

We have been able in *Onychocrinus* to study the ventral structure with unusual thoroughness in two of the species, and to demonstrate for the second time among the Flexibilia by perfect specimens the existence of the open mouth and pliant tegmen, by which they differ so sharply from the other grand divisions of the crinoids. The genus represents the extreme of the flexible characteristics on which the order is based; the lower calyx plates are rather thin, while those of the free rays are very deep and strong; but the whole crown in some of the species could assume any position, from a complete horizontal distension of calyx and rays to one with the rays vertical and closely folded. We find specimens in all varieties of these positions, and on account of such extreme changes the usual measurements are not of much service. A useful basis of comparison is found in the relative length of the ray below the fork, and of the main trunks or rami above it; there is a very well-marked progressive variation in regard to this character through a line of species, from those with very short rami in the Burlington to some in the Keokuk and Kaskaskia with rami two or three times as long as the ray below them.

Lyon and Casseday proposed the genus upon the Keokuk species *exsculptus*, which represents the extreme form so well described by Meek and Worthen. The former authors did not include it in their species *ramulosus*, which they had previously described under

*Forbesiocrinus,* and which now represents one of the most important groups of the present genus. Hall did not recognize *Onychocrinus,* and put *asteriaeformis* under *Forbesiocrinus.* Meek and Worthen, on the other hand, referred not only this but some species of *Taxocrinus* to it, on account of having an anal tube which they then considered a special character of *Onychocrinus.*

If characters were to be given the same value here as in some other cases, it would be possible to subdivide this genus into several. It stands as a very distinct type, sharply differentiated from all other Taxocrinidae by its heterotomous arms. Included within this type are species characterized by three different kinds of heterotomy, and by very constant differences in the number of primibrachs and in the development of interbrachials, some or all of which under other circumstances would be held to be generic characters. Here, however, we have a highly specialized type limited in geological range to the Lower Carboniferous, and exhibiting many and rapid changes on approaching the extinction of the family. Under such conditions it may happen that characters which have been important elsewhere in the same family become subordinate or wholly worthless.

Other types have run the same course. There are cases where a species, just at the close of the life of a genus, has been known to exhibit a jumble of characters which at an earlier period in its history had been constant and reliable for several well-defined species. An example of this is seen in the Camerate genus *Dolatocrinus,* in which during the Onondaga epoch the number of arms was a good specific character, while in a rampant development in the Hamilton, on the eve of extinction, these same characters appear worthless,—irregular variations within the limits of species otherwise perfectly well-defined. Therefore it seems to me the most logical course to treat the present form as a somewhat comprehensive and vigorous generic entity, embracing a number of unusually well-marked species.

In 1902 I proposed to separate *O. asteriaeformis* from the genus because it differed from all the other American species in having the ramules unilateral, branching only to the outside of the dichotom instead of alternately from each side, and accordingly published the name *Oligocrinus* for that purpose. The considerations above mentioned have convinced me that such a course is undesirable under the circumstances. The Irish species *Taxocrinus polydactylus* of M'Coy, which is of this type, has the ramules branching only toward the inside of the dichotom, and there would be equal reason for creating a new genus for it. This would be a greater refinement than is justified with two such isolated species, and I think it preferable to abandon the name already proposed. A better reason could be given for making two genera out of those forms that would remain under *Onychocrinus,* which fall into some rather well-marked sections containing assemblages of species. Between two such species as *O. exsculptus* and *O. ramulosus* there is a difference in habitus, as well as in strong morphological characters, far greater than between the former and *O. asteriaeformis,* on account of which under some circumstances we should without hesitation propose a new genus.

But in view of the stronger distinctive character by which all the species of this type depart from the rest of the family, and by which they are so conspicuously united, I believe it the better practice to regard the differences in heterotomy as minor details, wholly subordinate to the more general plan. Adopting this course, the species form a compact, satisfactory genus, well limited geologically, one in which the leading forms are sharply differentiated from one another. Unilateral heterotomy is not uncommon in other groups; but bilateral, alternating heterotomy is a new feature pointing toward pinnulation, and the most characteristic species of the genus are those possessing it. Treating the former as in this case a minor variation, and separating *O. polydactylus* as a very extreme form imperfectly known, the species will form two groups, which from the two best known species representing them may be called the *exsculptus* group and the *ramulosus* group.

The first is the extreme and typical form on which the genus was founded, and under which it was discussed by Meek and Worthen, viz., the form with profuse interbrachials and a tendency to extend the free rays to resemble a starfish; the second is a form with equally prominent heterotomy, but having a very slight development of interbrachials and no tendency to horizontal extension, and also having much greater length of the rami. These represent the two extremes also found in *Taxocrinus,* from which they may well be derived by the addition of complete heterotomy in the arm branching—the *exsculptus* group from species like *Taxocrinus intermedius,* and the *ramulosus* group from the typical *Taxocrinus* like *T. macrodactylus.*

From an evolutionary standpoint sub-divisions of the two genera upon these lines might perhaps be an advisable procedure. The difficulty would be to find a dividing line in *Taxocrinus,* where the change from few to numerous interbrachials is so gradual. A still stronger objection is that the course of development of interbrachials is not the same in the two genera; for whereas in *Taxocrinus* it is by way of a progressive increase, maintained to the last, this is reversed in *Onychocrinus,* in which the later phases are those of retrogression—the most profuse growth of interbrachials being in the species from the lower half of the Lower Carboniferous. But at all events this distinction will make two rather conspicuous sections under *Onychocrinus.* The first group begins so far as we know in the Burlington and ends in the Keokuk, while the other begins in the Keokuk and ends with the family in the Kaskaskia; and there is a somewhat intermediate form in the St. Louis.

I have already alluded to the fact that the alternate branching of subordinate ramules is suggestive of pinnulation, the absence of which is such a remarkable characteristic of the Paleozoic Flexibilia. Not only so, but there is in the very last American species, on the eve of the extinction of the entire group, a more direct tendency toward pinnulation, by the frequent reduction of the intervals between the ramules to two brachials; a very slight further modification, reducing the intervening brachials to one or uniting them by syzygy, would produce a condition of arms nowise essentially different from that of a ten-armed comatulid. This condition is approached in a new species from Scotland, *O. wrighti,* found since the foregoing was written, which in the upper arm regions has some ramules alternating on every successive brachial.

The stem of *Onychocrinus* reached the maximum length for the Flexibilia, being longest in *O. ramulosus,* in which it attains a length of three feet. In *exsculptus,* where we also have it complete, it is considerably shorter.

Representing, as it does, a high specialization of the Taxocrinidae, the genus was not very long lived, being limited to the Lower Carboniferous; and it had its chief development in America. The Irish species, of which the known material is too meagre for critical study, is from strata probably corresponding to the later American rocks of that period. In the length of its free rays it is the most extreme form, but in the other characteristics it would go with the *ramulosus* group. We have fragmentary evidence of the existence of the genus in the Knobstone beds, but no trace of it has ever been found in the lower beds at Burlington. Two well distinguished species of the *exsculptus* type occur in the Upper Burlington, but the culmination of the genus was in the Keokuk. There three splendid and beautifully distinct species flourished in abundance, one apparently a lineal descendant of the Burlington species in the lower of the two Keokuk horizons; and the other two, types of the two groups, side by side in the same colony of the other and later Keokuk horizon. The St. Louis and earlier Kaskaskia formations have two intermediate species, and the later Kaskaskia, which marks the extinction of the genus, has a very distinct successor of the *ramulosus* type. The last is now represented by a similar species from the closely equivalent Hurlet limestone of Scotland.

Of the fifteen described species belonging to this genus, five are synonyms or insufficiently defined for identification. The remaining ten may be arranged as follows:

THE SPECIES OF ONYCHOCRINUS

- I. *Exsculptus* Group.
  - iBr numerous and well-developed.
    - Ramules unilateral, outside of dichotom. IBr 3.............. *O. asteriaeformis.*
    - Ramules bilateral, alternating on both sides of dichotom.
      - IBr 4; rami strongly diverging.
        - Rami short, with few divergent clusters of stout ramules.
          - Ramules at intervals of 3 or more.
            - Anal tube small .................................... *O. diversus.*
        - Rami longer, rays short and robust, clusters of stout ramules more than 5 in number.
          - Anal tube large ....................................... *O. ulrichi.*
        - Rami longer than main rays below, slender and gradually tapering.
          - Ramules delicate and clusters numerous.................. *O. exsculptus.*
- II. *Ramulosus* Group.
  - iBr few; areas chiefly filled by perisome.
    - Ramules bilateral, alternating.
      - Rami much longer than main rays below.
    - Small iBr frequent in higher axils.
      - Rami strong.
        - Ramules not divergent, long, branching at long intervals and not forming clusters; united to main ramus for several brachials or connected by small iBr.
          - IBr 3; IIBr 4 or more.............................. *O. ramulosus.*
    - Small iBr rare in higher axils.
      - Rami slender.
        - Ramules divergent; delicate, in clusters at intervals of 3, or 2 in upper part.
          - IBr variable, 3 or 4; IIBr 3.
            - Rays massive ........................................ *O. magnus.*
            - Rays relatively slender ................................ *O. distensus.*
      - Rami strong; ramules thick, not in clusters, at intervals of 3 and 2.
        - IBr 3. IIBr 3 and 2................................. *O. pulaskiensis.*
        - IBr 4. IIBr 2; ramules at intervals of 3, 2 and 1.............. *O. wrighti.*
        - IBr 5 or more.
          - Ramules unilateral, inside of dichotom.............. *O. polydactylus.*
- Insufficiently defined ............................................ *O. semiovatus.*

### **Onychocrinus asteriaeformis** (Hall)

*Plate LXIV, figs. 1-10*

*Forbesiocrinus asteriaeformis* Hall, Jour. Boston Soc. Nat. Hist., VII, 1861, p. 320; Descr. New Species Crinoidea, p. 9.—Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, IX, 1865, p. 140.—Hall, Bull. 1, New York St. Mus. Nat. Hist., Photographic Plates, 1872, pl. 6, figs. 10, 11.

*Onychocrinus asteriaeformis,* Meek and Worthen, Geol. Surv. Illinois, II, 1866, p. 243.—Wachsmuth and Springer, Revision Palaeocrinoidea, I, 1879, p. 54.

*Oligocrinus asteriaeformis,* Springer, Amer. Geologist, XXX, 1902, p. 96; Jour. Geology, XIV, 1906, pl. 6, fig. 16.

The smallest species of the genus. Crown elongate when folded; but frequently extended in the form of a five-rayed star, with a broad, shallow calyx in the center. Rays below broad and stout, two and one-half times as long as the rami above; branching after 3 or 4 double series of interlocking IIBr beyond the axillary IBr into 2 small rami; these do not diverge, but continue about parallel and rather close together, giving off ramules on the outside of the dichotom only, tapering gradually to slender extremities and ending in an equal bifurcation. Ramules 3 or 4 to each ramus, long and slender, branching once as a rule; the lowest one sometimes branching twice at short intervals, forming a small cluster. Interbrachials well developed. Sutures slightly arcuate, often appearing straight in lower part of ray.

IBB low, in form of a thickened columnal. BB of good size, appearing in form of pentagons as high as wide. All brachials relatively short and wide. IBr 3. IIBr united by the inner margins directly or through small iBr to the extent of 4 or 5 pairs in mature specimens, but separating at the axillary in young. First ramule on third IIBr, with intervals of 3 and 4 brachials beyond. First iBr large, with 2 or 3 large ones in second range, diminishing in one or more successive ranges to a rounded crescentic margin about the height of IBr 2 or 3. Anal tube strong, with deep sub-central socket. Column large, tapering slowly from the calyx, and passing into alternating long and short columnals.

Dimensions of average of 9 mature specimens: Length of ray below fork, measured from IBB to axil, 25 mm.; of ramus, from fork to axil of terminal bifurcation, 10 mm.; diameter of calyx above IBr, 19 mm.; of base at column facet, 5 mm.

Hall did not recognize Lyon's genus *Onychocrinus,* and so placed this extreme form under *Forbesiocrinus,* which was his favorite dumping ground for Carboniferous Flexibilia. The species was not illustrated when described, but good figures of both type specimens, photographed from drawings by Whitfield, were distributed privately in 1872. I have given new figures of both, with an additional series of five specimens by which all the characters are amply illustrated. These are remarkably constant; in 19 specimens the number of IBr does not vary from 3, except in two rays.

This is the most extended of all the species in the spreading of the arms, and thus falls readily into the *exsculptus* group. Tested by the relative lengths of the main ray and of the rami above the fork, it forms the beginning of a series in which the length of the rami progressively increases until they equal and then greatly exceed the main ray. And it differs from them all in the unusual feature of having the ramules branch only to the outside—a structure which finds a parallel in the highly specialized Camerate species *Dichocrinus polydactylus*. It is otherwise well-distinguished from the other species occurring in the same horizon, *O. diversus*, by its 3 IBr and small, non-divergent rami.

A fact of individual growth which runs through the *Onychocrini*, to be noted in this form, is the progressive joining of the rays by interlocking of IIBr above the axillary. In young specimens they separate at once; then the first pair of IIBr are united, and so on until in mature specimens they are joined beyond the first ramule, and to the fourth or fifth pairs of brachials.

*Types.* One of Hall's originals (Pl. LXIV, fig. 1), formerly in the collection of Dr. C. A. White, is in the author's collection; the other (fig. 2), formerly in the collection of Rev. W. H. Barris, is in the Museum of Comparative Zoology at Harvard. The others figured are in the author's collection.

*Horizon and locality.* Lower Carboniferous, Upper Burlington limestone; Burlington, Iowa.

### **Onychocrinus diversus** Meek and Worthen

*Plates LXV, figs. 1-7; LXVII, figs. 11a, b*

*Onychocrinus diversus* Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, (1) XVIII, 1866, p. 256; Geol. Surv. Illinois, II, 1866, p. 243; *ibid.*, III, 1868, p. 492, pl. 17, figs. 5*a*, *b*, and text diagram.—Wachsmuth and Springer, Revision Palaeocrinoidea, I, 1879, p. 54; N. A. Crinoidea Camerata, 1897, p. 123.

A large-sized species. Crown short and broad; and with rays extended forming an irregular five-rayed star bilaterally differentiated by the anal interradius. Calyx comparatively small and depressed. Rays large, the part below the fork nearly twice as long as the rami above it; deeply rounded; free from about the second primibrach, and continuing about the same size from there to the second or third pair of secundibrachs. Rami strong, short, widely diverging, tapering to small ends. Ramules bilateral, branching in strong clusters alternately from both sides of the dichotom at intervals usually of 3 brachials; number of clusters rarely exceeding 5. Sutures but little arcuate, and in slightly weathered specimens appearing nearly straight on the main rays, but more curved above the division. Interbrachials well-developed, with strong plates in the first one or two ranges, followed by gradually diminishing plates curving over to a connection with the tegmen; leaving a broadly curved, crescentic margin connecting the rays and followed by perisome. Surface smooth, or finely granulose.

IBB low, visible above column, resembling a columnal. BB in form of large pentagons, with post. B much the larger, rising high between RR. RR and IBr of similar form, very thick, wider than long, diminishing gradually in length. IBr 4. IIBr 3 (exceptionally 4), interlocking in pairs, with somewhat zig-zag sutures (in young specimens less than the full number interlock) forming extensions of the ray of about the same width as the IBr; rays diverging about third pair of IIBr at a wide angle, more than 90 degrees, forming distinct rounded branches. Near the outer base of each branch a small ramule is given off from the short outer sloping face of axillary $IIBr_3$. The main branch continues from the longer, inner sloping face of the axillary, and a similar ramule is given off from the inner side of $IIIBr_3$; another on the outside on about the third brachial; and so on alternately to a total of 4 or 5 ramules (in mature specimens, fewer in young), ending in an equal bifurcation; the last two or three divisions are without much divergence. Each ramule bifurcates on the second or third plate, and again once or twice with short intervals, producing five or more ultimate arms to the ramule; these are rounded and short, forming clusters at the extremities of the main rami where they curve toward the ventral side and fold together in bunches like the fingers of a clenched fist. Brachials in the ramules, as well as main rami above IIBr, short and wide, and usually with arcuate sutures. All brachials from the first primary on becoming free are very deeply rounded, with a deep ventral furrow ramifying into the ramules. iBr in 3 or 4 ranges extending to second or third IBr. Anal tube apparently small, not preserved above first plate in any of the specimens, which shows that it was fragile and bordered by weak perisome. Column of moderate size; the enlargement at calyx slight, tapering gradually downward and passing into alternating, rather short columnals, which in mature specimens are more or less convex, the longer ones projecting above the others.

Dimensions of average large specimens, such as the type, figure 1: length of ray from IBB to top of angle of divergence—that is, the ray below the fork—35 mm.; of rami above the fork measured to axil of terminal bifurcation, 20 mm.; diameter of calyx, 30 mm.; of base at column facet, 8 mm.[1]

This species is typical of what may be called the extreme form of the genus, having widely distended free rays, and a considerable number of iBr plates curving inward over the margins, accompanied by a frequent complete horizontal extension of the whole crown. In this respect the description would apply as well to several species, which might be taken with it to form a fairly distinct group within this genus, viz., *O. asteriaeformis, O. ulrichi* and *O. exsculptus.* Meek and Worthen in discussing the reasons for separating the species from *Forbesiocrinus* (Geol. Surv. Illinois, vol. 2, p. 242) gave the following excellent picture of it:

> If we could open and spread out the rays of a *Forbesiocrinus* upon a plane as far in as to the second radial pieces, and then divide each of the interradial series of plates and fold them up so as to cover the vault, and apparently to some extent the free rays, somewhat in the manner suggested by Prof. Agassiz for the ideal conversion of an Echinoid into a Starfish, we would have a form very like the extreme *Onychocrinus.*

The ramules are in strong clusters of 5 or 6 fairly stout finial branches, but the clusters are few in number, not exceeding five counting the terminal one, and usually not so many. Also the clusters diminish in size distally; while the lowest may have 5 or 6 branches, those above that have progressively fewer, until the last equal bifurcation has two finials to each branch.

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[1] The same measurements will be made for all the species.

In general aspect, especially when the rays are horizontally extended, this species superficially resembles *O. asteriaeformis* of the same horizon and locality, but the differences between them are constant and decisive. *O. asteriaeformis* has almost without exception only 3 primibrachs; in 19 good specimens, having 68 rays preserved, only two rays have more than 3 IBr; while in 17 specimens of *O. diversus,* having 48 rays preserved, less than 4 IBr are found in only 8 rays. The species can be separated at once with a fragment showing the terminal part of the ray, not only by the small and non-divergent rami in *O. asteriaeformis,* but by the succession of ramules, even if only the outer margin of the ramus can be seen. In the latter, ramules will be found successively at intervals of 3 brachials (exceptionally 4); while in *O. diversus* the interval at that side will be 6 brachials (the intermediate ramule being on the opposite side), and the clusters of ramules will be very much larger and fewer than in the former species, in which there are from 8 to 10 clusters, against a maximum of 5 in this. Also *O. diversus* is much the larger species of the two.

The species is quite rare. Although the 17 specimens in my own collection and that of the Museum of Comparative Zoology form a good series for its study, these are substantially all that have been found among the collections made at Burlington in fifty years. The preservation of the specimens of the genus at this locality is not favorable for fine structural details; but these are amply supplied by the next species. I have figured the two types, one of which, showing the ventral side with the distal ends of the infolding clusters of ramules, has been further cleaned, exposing the posterior oral and some adjoining structures displaced (Pl. LXV, fig. 2). The other one, giving the dorsal view (fig. 1), is a very mature specimen, having all the IIBr interlocking in pairs. My figure shows some parts of rays not seen in the original figure in the Illinois Report; these were accidentally detached from the specimen, then in a fragile condition, when that figure was drawn by Mr. Roetter. In the fine specimen shown by figure 3 the clusters of ramules on the right posterior ray are somewhat obscured by a hard matrix, and I have restored them from another specimen, in which they are extremely well-preserved, and which shows the exact mode of branching. This specimen is not symmetrically extended, the anterior and right anterior rays being foreshortened; the latter is abnormal, having only 2 IBr.

*Types.* Meek and Worthen's originals are in the Museum of Comparative Zoology, Harvard. The other specimens figured and studied are in the author's collection.

*Horizon and locality.* Lower Carboniferous, upper Burlington limestone; Burlington, Iowa.

### **Onychocrinus ulrichi** Miller and Gurley

*Plates XXI, fig. 5; LXVI, figs. 1-10; LXVII, figs. 1-10; LXVIII, figs. 1-6*

*Onychocrinus ulrichi* Miller and Gurley, Jour. Cincinnati Soc. Nat. Hist., XIII, 1890, p. 17, pl. 3, figs. 2, 3; Descr. New Species Crinoidea, p. 17, pl. 3, figs. 2, 3 (author's ed.); Geol. Surv. Indiana, 16th Rep., 1890, p. 339, pl. 3, figs. 2, 3.—Wachsmuth and Springer, N. A. Crinoidea Camerata, 1897, p. 123; Springer, Jour. Geology, XIV, 1906, p. 469, pl. 4, figs. 1-5.

*Onychocrinus cantonensis* Miller and Gurley, 16th Rep. Geol. Surv. Indiana, 1890, p. 359, pl. 7, fig. 9.

A large species of the type of *O. diversus,* and representing it in the succeeding formation; differing from it only in minor details. It has a relatively larger calyx; the rays are rather stouter and rami relatively longer, with clusters of ramules more extensively developed, reaching the number of 7 or 9 in maximum specimens, against not over 5 in similar specimens of *O. diversus.* The anal tube is stronger, the socket in post. B larger and subcentral, nearly as wide as its distal edge; iBr more numerous and reaching higher up, even sometimes to the IIBr. Comparison of the figures of mature specimens of

*O. ulrichi* like figures 1, 2, 3, 10 of Plate LXVI with those of similar specimens of *O. diversus* on Plate LXV will show the differences better than detailed measurements. As to these characters there are various intermediate stages, so that if the specimens were found together in the same horizon it would be almost impossible to distinguish them. Maximum specimens in the same condition as the type of *O. diversus* measure 40 mm. length of ray to the fork; 30 mm. length of ramus above fork; diameter of calyx, 38 mm.; of base, 9 mm. The column is rather larger, with less convex nodal ossicles; we have it to a length of 15 inches (only part shown in the drawing) in the specimen figured 4, Plate LXVI, at which point cirri begin to appear, indicating a probable length of three or four inches more.

The number of IBr is remarkably constant at 4; in 30 specimens with substantially all the rays visible, 16 are regular throughout, 11 vary in one ray, and 3 in two; or out of 146 rays, 135 have 4 or more, and only 11 have 3.

The affinities of this Keokuk species are far closer with the antecedent Burlington form than with either of the other two Keokuk species, which occur at a slightly higher horizon. It is one of the leading fossils in the prolific crinoid bed of Indian Creek, Montgomery County, Indiana, where it has been collected in two colonies about a quarter of a mile apart. The horizon is in the upper part of the Keokuk group, doubtless representing the geode bed, but not quite so high as the Crawfordsville bed. The crinoids were imbedded in a thin stratum of bluish argillaceous limestone, very homogeneous in texture, and soft enough to be easily worked with tools; they had been deposited in very quiet waters, so that the stems and arms were intact and the finer structures beautifully preserved. The specimens were abundant, about 75 having been recovered in good condition for study. With these favorable conditions it has been possible to make a number of preparations which have thrown a flood of light upon structures previously unknown in this genus, and have furnished the means of illustrating the tegmen and the relations of the anal series to it, probably for the whole group, with a completeness not before dreamed of.

Up to the time of these discoveries nothing was known of the ventral structure of *Onychocrinus,* although from analogy with *Taxocrinus* its disk was supposed to be composed of a soft skin with calcified ambulacra. This was confirmed, and in 1906 I published an account of it with figures of some of the specimens (Jour. Geology, vol. 14, p. 467). The limits of that paper did not admit a full exposition of the material, a selection of which has now been assembled and fully illustrated upon Plates LXVI, LXVII and LXVIII.

In addition to the type, now further cleaned since the first figure was published by Miller and Gurley, there are figured on Plate LXVI a series of specimens showing the general form and proportions, with instructive details of the rays, ramules, interbrachial and anal structures, in individuals of different stages of growth from very young to mature, all in vertical position with the arms erect. The external appearance of a perfect anal tube with the bordering perisome in good condition on both sides, as well as full details of the mode of branching in the clusters of ramules, are shown by the beautifully preserved specimen at figure 2. Figure 4 has the stem to a distance of about twelve inches more than is shown in the drawing; it continues with about the same alternation of short, non-projecting columnals until toward the distal end, where they become more equal, and small scattered cirri begin to appear; it was probably 18 to 20 inches in total length. The growth of interbrachials is shown by the contrast between figure 8*a* with its single plate in the axil, and figure 3 with 20 or more iBr rising on either side in a deep crescent to the height of the second or third IIBr. The series also shows a corresponding progression in the lateral union of the pairs of IIBr forming the continuation of the main ray, from a partial attachment of one pair in the young to a union of three directly, and of more by the aid of iIIBr in the mature.

Plate LXVII contains a series of preparations for the special illustration of the tegminal, anal, and oral structures. Figure 1 gives a dorsal view of the anal tube and the form of the posterior basal, as seen upon a specimen with rays horizontally extended. Figure *2a* is a ventral view of a similar specimen with the tegmen preserved but somewhat broken down, including the plated perisome, parts of ambulacra, oral plates and those connecting with them; and especially the anal tube, which is quite perfect, curving to the right behind the posterior oral, with the folded perisome attached for its full length at one side. All of these appear more clearly in the enlarged figure of this central portion, *2b;* the fold in the perisome at the right of the tube shows with accuracy the relation of the tube plates to the perisome, and that when in life this articulated series of strong plates was erected it simply raised a portion of the flexible integument into a conical tube, forming the rectum, to a height where the excrement could be discharged away from the oral center.

In figure *3a* the oral structures have fallen to the rear, partly overlying the tube with the perisome still attached at both sides; and *3b,* an enlarged view from a more favorable angle, shows the tube to its distal end as if it were imbedded in the perisome; the aperture cannot be identified, being doubtless always closed by pressure upon the perisome. Figure 4 is a detail from a large specimen in which the exact mode of connection of the perisome to the margin of the anal tube is shown; it is attached on both sides in its original position for a distance of four or five plates; at the fifth the tube has fallen over nearly at right angles, and the upper part has slipped away from the perisome, leaving exposed the grooved margin by which it was attached. In figure 5 we have the inner side of a tube from near the distal end, with the tubular wall of perisome attached but flattened by pressure; the cross-section shows how it was attached to both margins of the anal tube plates. This figure leaves no doubt that the series of strong, articulated plates is really the backing and support of the rectum formed by a conical protrusion of perisome, thus constituting the anal tube of which these plates are the outer wall. Figure 6 is a fragment of similar tube plates of *O. exsculptus,* with the marginal crease for attachment of perisome well exposed. The tube is always found curved to the right under the edge of the posterior oral or its supporting plates.

Passing now to the oral structures, we have in figure 7 an almost complete tegmen, with very little disturbance of the parts out of their natural positions. The tegmen of the Flexibilia is so fragile that in most cases where the ventral side can be got at in the specimens the parts are broken down and piled in a confused mass at the bottom of the calyx. Such was the case with several of this species used during the earlier searches of Wachsmuth and myself for the ventral structures; after patiently excavating the matrix with which every one of these cavities was solidly filled, we would come to a large, uncouth looking object at the very bottom having no apparent relation to anything around it. Nothing more being seen, we would give that up as a failure and try another, only to be followed by many such disappointments. That large, uninteresting object, which I supposed to be some foreign body accidentally lodged there when the crinoid was imbedded, was the posterior oral entirely displaced, with the other parts disintegrated beyond recognition; but I did not know it then, nor for long afterwards.

It was many years after the acquisition of these specimens, and after the fruitless efforts above described to find the ventral structure, that I again took up the search in the Indian Creek specimens. They were the most encouraging because of the firm and even texture of the matrix, and its freedom from pyritous nodules and incrustations which destroy the finer structures in the cavities of the Crawfordsville specimens. A number of them were in horizontal position with the rays extended, but always adhering most firmly to the matrix at the ventral side, and had therefore been cleaned with the dorsal side free, as in figure 5 of Plate LXVIII. I took the most promising of these, seventeen in number, bedded them in cement by the dorsal side so they could be manipulated without breaking, and proceeded to remove the matrix from the ventral side and explore the cavity with fine tools. It was a laborious and tedious task, covering several months, which could not be entrusted to another because every stroke had to be watched by the person most interested, so that he might know at first hand what was encountered, and be able to interpret the structures as they were disclosed.

The first specimen was unproductive (Pl. LXVIII, fig. 4), showing nothing but the posterior oral standing nearly on end, which as before I did not recognize. The next was figure 7 of Plate LXVII, a medium-sized specimen with rays and calyx unusually widely distended; working inward along one of the rays after uncovering the arms, I discovered the ambulacrum, and then the finely plated perisome; following carefully with these for a guide, the structures were one by one exposed until the whole appeared as now seen in the figure—a specimen worthy to rank with our celebrated specimen of *Taxocrinus intermedius*, which first disclosed the real nature of the Flexibilia tegmen as distinguished from that of the other orders. I have given this somewhat minute account because these structures now look very plain and simple in the figures, and it might not be realized from inspecting them that every one of these delicately constructed tegmens was buried in a fine calcareous matrix, from which it had to be exposed by long and careful work with sharp tools and fine needles, much of it under a magnifier.

With that of figure 7 for a guide, the other specimens could be exposed with greater confidence, and the structures were afterward found more or less intact in several, as shown by the figures; some especially clear in one detail and some in another, until they furnished about all the information one could hope to obtain from fossils. In none of the others were the structures so little disturbed as in figure 7, although figure 10 of the same plate, and figure 1 of Plate LXVIII, are almost as good for the general picture.

Turning now to a more detailed inspection of the figures on Plate LXVII,—figure 7 shows the correct relation of the several parts of the tegmen in its entirety; the strong ambulacra, with their large, elongate, alternating plates, are intact, and the oral pyramid between whose plates they converge to enter the mouth is almost in place; three of the small triangular, anterior orals, two of which are well seen from the view in which the specimen was photographed for drawing, are apparently exposed almost as they were in life; the fourth is displaced, being pushed in under the one at the left so that only a small point of it can be seen in the figure. The most striking and unexpected thing about this tegmen is the extraordinarily disproportionate size of the posterior oral. In figure 7 it is nearly three times as large as the area of the other four combined; it is a relatively huge triangular or lance-head plate, with the other four orals converging around its blunted apex, at which there is an aperture where they opened out; the posterior ambulacra follow along its sides, and the anal tube, curling to the right, usually lies close to its base or large end. The rear corners are more or less truncated or cut away, and from them a series of large, gradually diminishing buttress-like plates pass to the rear next to the line of the posterior ambulacra; only one of these is visible in figure 7, the others being broken off; but they are intact and in position in figures *2a, b,* and appear to a greater or less extent in the other figures.

We have nothing analogous to these in the pliant tegmens of the Recent crinoids, but I suppose them to serve in some way as a support for the large oral. As they appear in these preparations the oral plates seem somewhat irregular in shape; this is in part due to their accidental positions, especially the large posterior oral which is usually more or less foreshortened; the smaller ones are found partly imbedded in the debris of the broken down perisome, so that we see them variously exposed and from different angles of view; also they may vary in size or shape in different specimens. In figure 7 the posterior oral is transversely bisected, which is not observed in any other case. That this plate is a madreporite rather profusely perforated is best shown by figures 9*a, b,* which are enlarged views of the central part of a small tegmen in which the pores are quite plain.

The greater portion of the disk was clearly membranous, with calcareous spicules or granules imbedded in it; except at the oral center and the ambulacral regions, which are occupied by rows of large, elongate, alternating plates more or less tumid exteriorly, and keeled on the under surface as if for lines of muscular attachment. The ambulacra extend from the oral center along the rays to the point of bifurcation, beyond which they have not been traced; but they no doubt follow the arms in a modified form. The three anterior ambulacra pass in between the bases of the four small orals, much as they do between the plates of the oral pyramid in *Holopus* (Pl. A, fig. 8). The two posterior ambulacra first meet the outer corners of the large oral, thence run along its edges and pass in toward the mouth at the junction between it and the smaller orals.

Whether these strong alternating plates were covering pieces arching over the food grooves, or were merely some kind of sub-ambulacral plates forming a support for more delicate plates which were not preserved, or for an ambulacral structure composed only of soft parts, I am unable to determine. The variation in size and shape of these structures in the living crinoids is very great, and there is no reason why plates as large as these may not have served as covering pieces, opening out when the orals did to admit the inward passage of the food-bearing currents. The membranous connecting integument between the ambulacra was reinforced by a close growth of calcareous particles, similar to what has been observed in *Taxocrinus, Uintacrinus,* and the disks of many Recent crinoids (fig. 9*a*). It extends far out along the rays, bordering the ambulacra as far as they have been traced. It is extremely frail in the fossil, and is of a slightly darker color than the calyx plates.

Figure 8 throws further interesting light upon these structures, being the under or opposite side from that which we have seen in the others. The preparation was made by removing the calyx plates from the dorsal side—as if the specimen in figure 1 were stripped of its plates. We see the under side of the posterior oral, somewhat rough or wrinkled, and of some of the others at the angles between the ambulacra; also the large opening, or mouth, which is roofed over by the pyramid of small orals in figure 7; and the keeled under side of the ambulacra is quite plain.

Figures 11*a, b* are from a dissected calyx of *O. diversus* showing the form of the posterior basal, with its rounded upper margin, and exterior socket supporting the anal tube-plates; it is further interesting here as showing the much smaller size of the tube in this species than in *O. ulrichi,* where the socket occupies about the entire distal width of the plate (figs. 1, 4).

On Plate LXVIII, figures 1, 2 and 3 give further views of the same tegminal structures; and figure 1 an especially good picture of the distal aspect of the clusters of folded arms, as they are also seen in figure 4. The latter, in which no part of the tegmen can be identified except the foreshortened posterior oral, is important for the unusual way in which it exposes the interbrachial system. Although extended almost horizontally, the margins of the rays, and of the interbrachial areas between them, are bent inward in a peculiar manner (as if especially intended to illustrate Meek and Worthen's description of the *Onychocrinus* plan), so as to bring into view the interbrachials around the entire margin from the first ramule of one ray to that of another; in some of these interradii there are 25 plates.

Figure 5 is the dorsal view of a very symmetrical and horizontally extended specimen showing the relative proportions of calyx and rays when in that position, for comparison with similar specimens of *O. diversus.* Figure 6 is an attempt at restoration of the tegmen from the evidence of all the foregoing preparations, with special reference to the position and functions of the anal series of plates as a backing or support of the rectum, which is a conical extrusion of the perisome back of the posterior oral, curving to the right as we always find it. The number of these plates, about 13, and their relative size, are as actually found in large specimens with the tube intact; and they are sufficient when erect to support the tube at a height and in a direction to effect the discharge of the excrement entirely away from the mouth. This must be considered in connection with text-figure 8,[1] showing the manner in which the left posterior ray is grooved by pressure against the tube.

Miller and Gurley's *O. cantonensis* is a young specimen of this species from the equivalent horizon in Washington County. I have figured their type (Pl. LXVI, fig. 9), and along with it a mature individual from the same locality and horizon (fig. 10); the interbrachials of the latter are not all preserved in place.

*Types.* Miller and Gurley's original and the type of their *O. cantonensis* are in the University of Chicago; the others figured and studied are in the author's collection.

*Horizon and locality.* Lower Carboniferous, upper part of Keokuk limestone below the Crawfordsville beds; Indian Creek, Montgomery County, and Canton, Washington County, Indiana.

## **Onychocrinus exsculptus** Lyon and Casseday

*Plates LXIX, figs. 1-9; LXX, figs. 1-7; LXXI, figs. 1, 2*

*Onychocrinus exsculptus* Lyon and Casseday, Amer. Jour. Sci., (2) XXXIX, 1860, p. 78.—Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, IX, 1865, p. 140; Geol. Surv. Illinois, II, 1866, p. 247; *ibid.*, V, 1873, p. 498, pl. 14, fig. 4.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 55.—White, 11th Rep. Geol. Surv. Indiana, 1882, p. 365, pl. 40, fig. 1.—Quenstedt, Handbuch Petrefactenkunde, 1885, p. 947, pl. 75, fig. 27.—Springer, Jour. Geology, XIV, 1906, p. 474.

*Forbesiocrinus ? norwoodi* Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1860, p. 389.

*Taxocrinus norwoodi,* Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, IX, 1865, p. 142.

*Onychocrinus norwoodi,* Meek and Worthen, Geol. Surv. Illinois, II, 1866, p. 245, pl. 17, fig. 3, p. 247, text-fig. 26.

*Forbesiocrinus monroensis* Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1861 (1862), p. 130.

*Onychocrinus monroensis,* Meek and Worthen, Geol. Surv. Illinois, II, 1866, p. 244, pl. 17, fig. 7.

Type of the genus.

Of the type of *O. diversus,* but still more elongate, and attaining a larger size. Rami longer than the ray below fork, slender, tapering gradually to fine terminals; ramules in numerous clusters, small and delicate. Anal tube strong, with socket deeply indented, having a slightly raised margin, and located mostly on right side of post. B. Column large, long, tapering gradually from its proximal enlargement of uniformly very thin ossicles to alternating columnals, with narrow, convex, crenulated rim on the nodals; irregular cirri toward the distal end; otherwise generally similar to that of the last two species. Average dimensions of 6 mature specimens: Ray to fork, 45 mm.; ramus above fork, 56 mm.; diameter of calyx, 35 mm.; of base, 10.5 mm. Maximum specimen; ray 50 mm.; ramus, 75 mm.; total length of crown, 125 mm.; clusters of ramules, 13 or more. Column of mature specimen, 550 mm. (22 inches) long.

Comparison of the figures, as well as the dimensions above given, with those of the two preceding species, will show at once that this species is far more distinct from them than they are from each other, and that the striking and decisive difference is in the increase in length of the main ray divisions or rami. The dimensions of these in representative mature specimens of the three species and *O. asteriaeformis* are:

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[1] P. 51.

| | Ray | Ramus | Diam. of calyx | Base |
|---|---|---|---|---|
| *O. asteriaeformis* | 25 | 10 | 19 | 5 |
| *O. diversus* | 35 | 20 | 30 | 8 |
| *O. ulrichi* | 40 | 30 | 38 | 9 |
| *O. exsculptus* | 45 | 56 | 35 | 10.5 |

Thus it appears that while in the two earlier species the ramus was from 60 to 43 per cent shorter than the ray, in this one it is 25 per cent longer; with this increase in length the rami are proportionally more attenuate, and the clusters of ramules much more numerous—being in mature specimens from 13 to 15 as against 7 to 9 in *O. ulrichi,* and 3 to 5 in *O. diversus.* Thus in all these related characters there has been a progressive increase in the direction of elongation of the rami. The much greater delicacy of the ramules will distinguish this species in a mere fragment, and also in the young where the other differences are not so marked. The species also attains a larger size than the others, a maximum specimen being 125 mm. in total length of crown, against 70 mm. in *O. ulrichi.*

In this species also the number of IBr is substantially constant at 4, the variation being about five per cent in upward of 100 specimens; among these is an occasional ray with 5 IBr, though most of the variation is to 3. Plate LXX contains a selection of figures of specimens from the same colony in various stages of growth, by which all these characters are beautifully illustrated. And on Plate LXXI, I have given a figure of two specimens just as they lie on the slab together, one showing the stem studded with small cirri toward the end, and the other having the stem entirely complete, with its strong cirri at the root. These figures, with a scale to correspond, are reduced to about half the natural size; so it can be seen that the complete stem is about 22 inches long.

The ventral structure is the same as has been described for *O. ulrichi,* but is very rarely seen, notwithstanding the abundance of specimens at the typical locality. Figures 3, 4, 5 of Plate LXIX represent all of it that has ever been discovered. Figure 3 is from one of Lyon's specimens, upon which he made an excellent description of the vault, to the extent of identifying correctly the ambulacra, and the small irregular granulose "interstitial pieces lying in the fields bounded by the five rays," which he says "are composed of two rows of large granular pieces, one now alternating with the other" (Amer. Jour. Science, vol. 29, 1860, p. 79). Figure 5 shows all the ventral structures except the small orals, which are doubtless buried in the perisome; it also gives an instructive view of the clusters of ramules, showing how they diminish in the number of ultimate arms from 10 to 12 in the lower, to only 2 in the upper; six clusters are visible on the inside of the long ramus at the lower side, and there were one or two more, which would make at least 15 clusters for both sides of the ramus.

It was upon this species that Colonel S. S. Lyon founded the genus *Onychocrinus* in 1860. He recognized and correctly described its essential characters, viz., the long rays, with two gradually tapering branches fringed on either side with alternating clusters of what he called "pinnules." The widely extended rays, together with the traces of radiating ambulacra in the vault, impressed him strongly as forming a probable connecting link between the crinoids and star-fishes.

Lyon was a very ardent student of the crinoids. Most of his descriptions, including those under this genus, were not illustrated, from lack of means to procure the printing of the necessary plates. He prepared, however, excellent drawings of all his type specimens, and arranged them upon twenty-three plates, intending to bring out a monograph of the crinoids he had already described, together with a number of other species for which he had prepared descriptions which were never published. This project was interrupted by the Civil War, in which he served with distinction as an able officer, and after it was over his wounds and failing health prevented him from resuming the work. When in after years I acquired his collection from his family, these drawings were courteously turned over to me by his son, Mr. Victor W. Lyon, of Jeffersonville, Indiana, and I have much pleasure in publishing now his original figures of the two species of *Onychocrinus*. These show the excellent character of the work at that early day, which, while published under the joint names of himself and Casseday, was actually for the most part done by Lyon alone.

Figures 1, 2 of Plate LXIX are Lyon's original drawings of *O. exsculptus*,—figure 2 from a specimen in his collection, and figure 1 from another belonging to some one else, of which he had a plaster cast; its location is unknown. These specimens were from Crawfordsville, and with them in his collection were several others from the same locality, including the original of his figure 3; but although the description gives as one locality Clear Creek, Hardin County, Kentucky, there was not in his collection any specimen of this species definitely so labeled, or which was not recognizable as unquestionably from Crawfordsville; and I have not seen a specimen of it in any of the other collections made from Kentucky. Nevertheless it is highly probable that Lyon's statement of locality is correct, as *O. ramulosus*, the other Crawfordsville species, is represented by authentic specimens from Hardin County, and the present species has been found in the typical Keokuk of the Mississippi region.

Meek and Worthen in 1860 described under *Forbesiocrinus* ? *norwoodi* an imperfect specimen from the Keokuk limestone at Nauvoo, Illinois, and another in 1861 (1862), *Forbesiocrinus monroensis*, from the Keokuk of Monroe County. Both were later redescribed and figured side by side in volume 2, Geology of Illinois, where *O. norwoodi* is by mistake stated to be from Monroe County also. It is plain that these specimens, which I figure on Plate LXIX, figures 7, 9, represent the young and mature stages of the present species. This is confirmed by the appearance of a third much better specimen in the Cox collection, found near Keokuk, Iowa (fig. 8), which has all the proportions and general characteristics of the Crawfordsville specimens.

As showing how little this group was then understood, Meek and Worthen in describing their *F. monroensis*, which has the anal tube finely preserved, were much perplexed by its appearance, describing the tube as a " false arm, arising directly from the summit of the upper truncate side of the largest subradial. It seems even to be inserted into a sinus in the upper side of the subradial, yet one can scarcely believe it is anything but one of the smaller divisions of the arms, accidentally broken off and placed in that position." And they said the anal pieces were unknown. In the revised descriptions of 1866 they referred both species to *Onychocrinus*, and correctly interpreted the anal side in *O. monroensis*, which they found to be the chief means of distinction from *Forbesiocrinus*. They also admitted that *O. norwoodi* was probably identical with *O. exsculptus*; and the only differences they could point out between it and *O. monroensis* were its larger size, and " having the two divisions of each ray, after they divide in the last primary radial, continued on for some distance closely united instead of abruptly diverging." This latter, as my figures on Plate LXIX show, is a difference due solely to the growth of the individual. This, I think, effectually settles the status of these two species as synonymous, and leaves us with the three clearly valid species from the Keokuk formation.

*Types*. Author's collection.

*Horizon and locality*. Lower Carboniferous, Keokuk group; Crawfordsville, Indiana; Keokuk, Iowa; Nauvoo, and Monroe County, Illinois.

### **Onychocrinus ramulosus** (Lyon and Casseday)

*Plate LXXII*

*Forbesiocrinus ramulosus* Lyon and Casseday, Amer. Jour. Sci., XXVIII, 1859, p. 237.—Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, 1865, p. 140.—Quenstedt, Handbuch Petrefaktenkunde, 1885, p. 947, pl. 75, fig. 26.

*Onychocrinus ramulosus,* Wachsmuth and Springer, Revision Palaeocrinoidea, I, 1879, p. 55.—White, Geol. Surv. Indiana, 11th Rep., 1882, p. 366, pl. 39, figs. 2, 3.—Wachsmuth and Springer, N. A. Crinoidea Camerata, 1897, p. 75, table B, fig. 7.

Attaining a large size. Crown elongate, height to width in mature specimen as 3.7 to 1. Rays strong, short, broadly rounded; free from about IBr$_2$. Rami very long, two and one-half times as long as the ray below them; strong, tapering very gradually to fine terminals ending in equal bifurcations. Ramules bilateral, strong, long, given off alternately at intervals of 4 and 3 brachials, branching again several times at long intervals of 3 to 6, and not forming clusters; there are 13 to 15 in mature specimens. Sutures strongly arcuate throughout and patelloid processes often strongly marked. Surface finely granulose, usually found smooth. Average dimension of five large specimens: Ray below fork, 35 mm.; rami above fork, 87 mm.; diameter of calyx at IBr$_3$, 33 mm.; of base, 14 mm.; average of same dimensions in four small ones, 11-14-10-6. So the relative elongation of the rami increases greatly with age.

IBB low, barely visible above the column. BB small in large specimens, but little visible except the post. B. RR and IBr similar in form and size, and, like all brachials throughout the ray, short and from two and one-half to three times as wide as long. IBr 3; IIBr to first ramule, 4, diverging in adjacent rami at a small angle and rarely united for more than one pair above the axillary. Higher orders of Br between ramules varying between 4 and 3; ramules bifurcating on third and fifth brachial, and beyond that up to five times at intervals of 4 to 7; they make only a small angle with the main ramus, being joined to it by direct suture or iBr for a distance of several brachials. iBr few, small and irregular, passing quickly into loose perisome, and in mature specimens developed in the higher axils to the seventh or eighth ramule. Anal tube small; socket on right side of post. B which is rather narrow distally. Column strong, with very gradual taper from calyx, passing to slightly alternating columnals; it is very long, enlarges again toward the end, and has a few good-sized cirri in the lower part. Length of column in a moderate-sized specimen, 36 inches—the longest known in the Flexibilia.

The distinctions between this form and that of the *exsculptus* group are so obvious that detailed comparison is unnecessary. It would be much more logical to make a new genus for it and the following three species than for the isolated *O. asteriaeformis.* Lyon and Casseday, having described the species as *Forbesiocrinus* in 1859, did not include in it *Onychocrinus* when proposing the genus in 1860; and the type specimen, with others accompanying it in the Lyon collection, still bore the label, *Forbesiocrinus,* when I acquired it. The species was first referred to this genus by Wachsmuth and Springer in 1879.

The progressive increase in relative elongation of the rami which was noted in the remarks upon *O. exsculptus* has in this and allied species proceeded far beyond the maximum attained in that species. While on an average of all the species of the *exsculptus* group the main rays exceeded the rami in length as 1.25 to 1, in the *ramulosus* group the rays are shorter than the rami by an average of 1 to 2.4.

The whole facies of the widely spreading rays—suggesting a starfish, with clusters of short arms resembling the talons of a bird—which so strongly arrested the attention of Lyon, is wanting in this species, where the calyx and rays have again the relative proportions of a very elongate *Taxocrinus*. It may in fact be readily derived from the section of that genus having few interbrachials, like *T. macrodactylus,* just as the *exsculptus* form may be derived from such species as *T. intermedius,* by adding to each the heterotomous arm structure; and I am by no means sure that from an evolutionary standpoint a division of genera upon these lines would not be the most logical. The difficulty would be in finding a dividing line upon this character in *Taxocrinus,* where the change from few to numerous interbrachials is so gradual.

The 3 IBr feature is absolutely constant in this species throughout large numbers of specimens; as is also the 4 IIBr of the first interval, wherein it differs not only from the *exsculptus* group, but from the other species of this. The tendency is to long intervals between the ramules and between their branches. The ramules are sometimes almost as large as the rami; they branch frequently and by more or less equal bifurcations as many as five times in very mature specimens, the subordinate branches also branching again. It is difficult in most cases to trace the full length of the ramules, as they are generally covered over by others and by the rami; but in the magnificent specimens 2 and 3 of Plate LXXII not only this but also the fine terminals of the ray are beautifully shown.

The arcuate sutures, giving the appearance of patelloid plates between the successive brachials, are more conspicuous in this than in any species of the whole family; the projecting lip, and the crescentic socket into which it fits, are unusually thick and deep, so that they do not disappear with ordinary weathering, as in many other species. There is scarcely a specimen in its natural condition in which they are not perfectly plain throughout the entire ray; and it requires considerable grinding before the straight suture is reached. Figure 10 of Plate LXXII shows where I have done this on a curved surface of the primibrachs.

The stem of this species is much longer than in *O. exsculptus,* and longer than is known in any other species of the Flexibilia. I have two specimens, not figured, in which it is preserved for 36 inches to near the root, indicating a length of over three feet in medium-sized specimens. In such a mature specimen as figure *2a* it was probably much longer.

Nothing is known of the tegmen in this species. The condition of the specimens is not favorable for discovering it, as the rays are usually closely folded. Nevertheless I have explored two or three to the bottom of the cup without finding any definite structure except some rather small plates resembling orals; and I am of the opinion that the perisome was very fragile, and the orals small. There is no sign of such large plates as the posterior oral of the *exsculptus* group. It is not improbable that we should find here a quite distinct tegmen; the perisome must have been weak, for among numerous otherwise good specimens we rarely find the anal tube preserved beyond one or two plates.

From the extraordinary development of iBr in the higher axils (in one specimen to the eighth ramule) there must have been an extension of perisome along the rays such as is not known in any other species of the Flexibilia.

This species occurs in the same layers with *O. exsculptus,* in the great crinoid colony at Crawfordsville, where it is nearly as abundant. The present studies were made from about a hundred selected specimens which show remarkable constancy of characters, there being scarcely any variation among them except that due to age, as shown by the series of figures on Plate LXXII. I figure also a couple of abnormal specimens; one with the left lateral ray unbranched (fig. 11), and the other with a sixth ray doubled and wedged into the interbrachial area between the left posterior and left anterior rays (fig. 12). Lyon recorded the species from Clear Creek, Hardin County, Kentucky; but his description was made upon a good series of specimens from Crawfordsville. I have reproduced his drawing of the principal type specimen made for his monograph (Pl. LXXII, fig. 1). It does not well represent the arcuate sutures, which are much more conspicuous in the specimen, but it gives in general an excellent picture of the species. The specimen of figure 5 was among some other crinoids known to be from Barren County, Kentucky, and there is no reason to doubt its occurrence there, as the beds are typical Keokuk.

*Types.* Author's collection.

*Horizon and locality.* Lower Carboniferous, high in the Keokuk group; Crawfordsville, Indiana; Clear Creek, Hardin County, and Barren County, Kentucky.

### **Onychocrinus magnus** Worthen

*Plate LXXIII, figs. 1-4*

*Onychocrinus magnus* Worthen, Geol. Surv. Illinois, VI, 1875, p. 520, pl. 31, fig. 5.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 55.

A robust form with massive main rays, intermediate in the principal characters between the *exsculptus* and *ramulosus* groups. It has the distended rami and small ramules of the former, with the few interbrachials in the main axils and the greater relative length of rami of the latter. The single large interbrachial is directly followed by plated perisome (Pl. LXXIII, fig. *2a*), and this is probably the case in the higher axils, which have but one solid plate instead of many as in *ramulosus*. The number of primibrachs is unstable, being 3 or 4 in nearly equal proportions. Dimensions from average of 4 specimens: Length of ray to fork, 21 mm.; of ramus above fork, 42 mm.; diameter of calyx at $IBr_3$, 28 mm.; diameter of base, 9 mm.; number of ramule clusters, 9 to 13.

The type specimen is an unusually large and mature specimen; as originally figured in volume 6 of the Illinois Reports, plate 31, figure 5, it did not show any ramules, but with the further preparation I have given it they are now plainly exposed (Pl. LXXIII, fig. 1). This specimen has the arcuate sutures in profusion, the original surface having been protected by a fine clay matrix; but the other specimens figured were in a hard limestone exposed to weathering, by which the superficial curving of the sutures was to a large extent obliterated (figs. *2a*-4). But figure *2b*, from a ray not exposed to weathering, shows the sutures as strongly curved as in the type.

*Type.* In the Illinois State collection at Springfield.

*Horizon and locality.* Lower Carboniferous, St. Louis group; near Waterloo, Monroe County, Illinois, and at St. Louis, Missouri.

### **Onychocrinus distensus** Worthen

*Plate LXXIII, figs. 5-8*

*Onychocrinus distensus* Worthen, Bull. 1, Illinois St. Mus. Nat. Hist., 1882, p. 31; Geol. Surv. Illinois, VII, 1883, p. 307, pl. 29, fig. 5.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 3, 1886, p. 145.

A medium-sized species, also intermediate between the types of *O. exsculptus* and *O. ramulosus;* in general appearance similar to the former, but differing in the small number of iBr and longer rami. IBr variable, 3 or 4. iBr consisting of one large plate in the first axil followed by perisome, but none so far as observed in the second. Anal tube rather small. Dimensions from average of 8 mature specimens: Length of ray to fork, 18 mm.; of ramus above fork, 40 mm.; diameter of calyx at $IBr_3$, 24 mm.; of base, 7 mm. Clusters of ramules, 9 to 15.

This species as described by Worthen was founded upon a specimen from Monroe County, Illinois, in strata of the lower Kaskaskia now called the Renault formation. It formed a part of an interesting crinoidal fauna occurring at a locality on Prairie du Long Creek, which I have since carefully investigated.[1] The horizon has now been determined by the geologists of the U. S. Geological Survey to be equivalent to certain beds at Huntsville, Alabama, formerly considered to be St. Louis. The type specimen is imperfect, and for better illustration of the species I have made use of specimens from the Huntsville beds. After my plates were printed I obtained a large series of specimens from the original locality in Monroe County, by which the facies and relations of the species are well established.

While in its interbrachial structure and length of rami the species is of the *O. ramulosus* type, it may be considered an intermediate form between that and the *exsculptus* group, having some of the characters of both. This intermediate position is emphasized by the variable number of primibrachs; out of 13 specimens from the type locality, and all from the same colony, 5 have four IBr as in *exsculptus,* and 8 have three as in *ramulosus.* Like *exsculptus* it has a slender, tapering form, delicate ramules in clusters with short intervals between them; whereas in the direction of *ramulosus* it has a decided increase in the relative length of the rami, and there is a single large interbrachial plate distinctly outlined and firmly anchored in the axil, without trace of any others, but with indications of a finely plated perisome succeeding it. It lacks, however, the profuse development of plates in the higher axils which is so prominent in *ramulosus.* In well-preserved specimens there is a tendency to develop small nodes upon the higher axillaries.

The species has a well-defined stratigraphic position, and leads up to *O. pulaskiensis* of the later Kaskaskia beds, in which all trace of resemblance to *exsculptus* has been lost. It may also be considered as the successor of the more massive *O. magnus,* the type of which is from the same region but in the true St. Louis beds below the Renault horizon; that species is a similarly intermediate form, but the difference from this in massiveness of the rays is constant throughout a good series of specimens.

The species described by Meek and Worthen as *Forbesiocrinus semiovatus,* and afterward referred by them to *Taxocrinus,* proves to be an *Onychocrinus;* it was derived from somewhat lower strata in Hardin County, Illinois. The type specimen (Pl. LXXIII, fig. 7) is a young individual in poor condition; it may possibly be a variety of this species, but it is insufficient for specific determination.

*Types.* The original is in the Illinois State Museum at Springfield; the others figured are in the author's collection.

*Horizon and locality.* Lower Carboniferous, Renault formation in lower part of Kaskaskia Group; Monroe County, Illinois, and Huntsville, Alabama.

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[1] Smithsonian Misc. Coll. vol. 63, 1913, p. 15.

### **Onychocrinus pulaskiensis** Miller and Gurley

*Plates LXXIV, figs. 1-10; LXXV, figs. 15a, b*

*Onychocrinus pulaskiensis* Miller and Gurley, Bull. 6, Illinois St. Mus. Nat. Hist., 1895, p. 40, pl. 4, figs. 1, 2.

Perhaps *Onychocrinus parvus* Miller and Gurley, Bull. 3, Illinois St. Mus. Nat. Hist., 1894, p. 52, pl. 4, fig. 5 (Insufficiently known for identification).

A large species, of the type of *O. ramulosus;* but with more divergent arms, shorter intervals between ramules, ramules at a greater angle with the rami, and not connected with them by interbrachials. Rays deeply rounded; brachials relatively not so short and wide as in *ramulosus.* IBr 3; IIBr to first ramule 3 and 2. Ramules making a wide angle with rami, given off at intervals of 2 and 3; not forming clusters, but branching again at short intervals. Axillaries nodose. iBr, one large in the primary axil, followed by perisome; none in higher axils. Column thicker than in any of the other species, with convex and projecting nodal columnals. Average dimensions of 2 large specimens: Ray below fork, 31 mm.; ramus above fork, 63 (cannot be traced to end); diameter of calyx, 30 mm.; of base, 12. Number of clusters of ramules, 10 or more.

While this species in its chief essentials is clearly of the *ramulosus* type, the rounded divergent rami and ramules, with the latter standing almost at right angles to the main ramus, give to it a physiognomy quite distinct. Its one large interbrachial plate is more like that of *O. distensus,* which has a tendency toward some of its other characters. As the latest known American species of the genus, it exhibits in its short intervals between ramules the same tendency found in the accompanying Kaskaskia species of *Taxocrinus.* While not so constant as in *T. whitfieldi,* the bifurcation on the second brachial occurs with considerable frequency, sometimes in the IIBr, but more often higher up. Among a series of a dozen specimens it appears more or less in all; and it gives to the rays a zig-zag aspect which is heightened by the sharp nodes upon the axillaries. On well-preserved specimens these nodes are prominent, but on those that have been weathered, like the type and the large figure 2, they are not so plain.

The species is definitely characteristic for its horizon, and is well distributed. The best locality for it is in Pulaski County, Kentucky, but I have it also from Grayson and Breckinridge counties in that state, from Huntsville, Alabama, and from near Chester, Illinois. Its stratigraphic position is in the upper beds of the Kaskaskia Group, now called the Okaw formation.

No other species has been described from this horizon except *O. parvus* of Miller and Gurley, founded upon a single extremely young individual which is probably of this species (Pl. LXXIV, fig. 8). The authors did not attempt any comparison with other species, saying,—"This species is so much smaller than any other heretofore described that no comparison with any of them is necessary to distinguish it." My own numerous illustrations of the young stages of various species of *Onychocrinus* show how uncharacteristic they are; and there is nothing in the figure or description of this one by which it would be possible to identify a mature specimen, save only the possession of 3 IBr. Therefore, although the first described, I prefer to treat it as insufficiently defined, and to let this well-marked and distinctive species take the name of the later species, *O. pulaskiensis,* by the same authors. Their description throws but little light upon its real characters; but the type specimen, from the principal locality, is unquestionably the same as the fine series of specimens which I have illustrated.

*Types.* Miller and Gurley's original is in the University of Chicago. The others figured herein are in the author's collection.

*Horizon and locality.* Lower Carboniferous, Okaw formation, upper part of Kaskaskia Group; Pulaski, Grayson and Breckinridge counties, Kentucky; Huntsville, Alabama; and Randolph County, Illinois.

### **Onychocrinus wrighti** n. sp.

*Plate LXXV, fig. 14*

A large species, represented by a single specimen considerably injured by pressure.

Rays strong, deeply rounded and rather clumsy in appearance. IBr 4. Rami much longer than primary rays, stout with but little taper; strongly divergent, the IIBr entirely separating at the axillary and not being joined for any distance above. Ramules about 8; bilateral, given off alternately first at intervals of one or two brachials, but in the upper part of one ray every successive brachial is axillary, reducing the intervals of the ramules to those of pinnules; the ramules are very stout, almost as large as the rami and much resembling them in appearance; they branch secondarily on every second brachial, or upon successive brachials from 4 or 5 times in the lower ramules to a single equal bifurcation as usual at the distal end of the ramus. Sutures slightly arcuate in the main rays, becoming straighter distally. Interbrachials apparently not over one. Anal structures not preserved. Surface distinctly marked with fine wrinkles.

Length of ray to apex of axillary, 20 mm.; of ramus from axillary to terminal bifurcation, 50 mm.; diameter of column at base, 11 mm. Base too much distorted for measurement.

The solitary specimen on which this species is based was found by Mr. James Wright, Jr., of Kirkcaldy, Scotland, among the interesting collections made by him in the Hurlet limestone at Inverteil; and I have much pleasure in associating it with his name. It is the first typical *Onychocrinus* thus far found outside of the United States. Its occurrence along with *Hydreionocrinus, Cromyocrinus, Zeacrinus* of the *Z. wortheni* type, and *Synerocrinus,* points unmistakably to the closing epoch of the Lower Carboniferous, and this is confirmed by its structural affinities, which are decidedly with the latest Kaskaskia species, *O. pulaskiensis.* The general habitus, with the rather clumsy, slightly tapering rays, and the approach to pinnulation by the further diminution of intervals between ramules, produce a form of substantially the same type. The possession of four primibrachs (which distinctly appear in two uninjured rays), and ornamented surface, distinguish the species.

*Type.* In the collection of James Wright, Jr., Kirkcaldy, Scotland.

*Horizon and locality.* Upper part of Lower Carboniferous, Hurlet limestone,—correlated with the Kaskaskia of America; Inverteil, Scotland.

### (?) **Onychocrinus polydactylus** (M'Coy)

*Plate LXIV, figs. 11-14*

*Taxocrinus polydactylus* M'Coy, Syn. Carb. Fossils Ireland, 1844, p. 178, pl. 26, fig. 7 (*Cladocrinus* on Plate).—Roemer, Verh. Nat. Hist. Ver. Preuss. Rheinland, VIII, 1851, p. 366 (Separate, p. 10).—Morris, Cat. British Fossils, 2d Ed., 1854, p. 90.—Meek and Worthen, Proc. Acad. Nat. Sci. Philadelphia, IX, 1865, p. 140.—Quenstedt, Petrefaktenkunde Deutschlands, IV, 1876, p. 504, pl. 107, fig. 143.

*Cyathocrinus polydactylus,* Roemer in Bronn, Lethaea Geognostica, I, pt. 2, 1852-54, p. 237.

*Onychocrinus polydactylus,* Wachsmuth and Springer, Revision Palaeocrinoidea, I, 1879, p. 55.

*Poteriocrinus ? egertoni* Phillips, Geology Yorkshire, II, 1836, p. 205, pl. 3, fig. 39.—Quenstedt, Petrefaktenkunde Deutschlands, IV, 1876, p. 503, pl. 107, fig. 140.

*Isocrinus egertoni* Phillips, Palaeozoic Fossils Cornwall, 1841, p. 30.

*Cladocrinites egertoni,* Austin and Austin, Ann. and Mag. Nat. Hist., XI, 1843, p. 197.

*Taxocrinus egertoni,* Morris, Cat. British Fossils, 1843, p. 59.

A large-sized species, with very elongate crown. Rays long and slender, tapering slowly, the rami being nearly as heavy as the rays below them. Ramules thick, branching at intervals of two to five brachials at the inside of the dichotom. Calyx narrow, with few interbrachials. IBB covered by column. BB visible as fairly large pentagons. IBr 6 or more, narrowing slightly upward. Anal structure unknown. Column tapering rapidly from the calyx for a short distance, beyond which the thin columnals alternate with slightly projecting nodals. Height of maximum crown, estimated, 70 mm.

This is one of the two known representatives of the *Onychocrinus* type from British rocks, or others outside of America. Unfortunately we do not know enough of its structure to determine with certainty its generic relations, but it presumably has the weak anal side consistent with its greatly extended and divergent rays, and therefore will belong somewhere near the company in which I have placed it. M'Coy's figure in the Carboniferous Fossils of Ireland, which I have copied (Pl. LXIV, fig. 11), is a restoration, composed from three fragments which I have also figured, two of which undoubtedly belonged to the same specimen. I have placed them in their probable relative position, with the missing parts drawn in outline (fig. 12). We are materially assisted in this by the other fragment (fig. 13), which shows that there were at least six primibrachs, as the fifth one preserved in it is not axillary. These specimens are located in the Science and Art Museum, Dublin, and I am much indebted to Dr. R. F. Scharff, the Curator, for photographs and accurate casts from which to illustrate them.

There is no doubt that Phillips's *Poteriocrinus egertoni,* which is from the same region of the Irish Carboniferous, belongs to this species. Unfortunately the type cannot be found; it was in the collection of Sir Philip Egerton, afterward acquired by the British Museum, and Dr. Bather assures me that it has been an object of long and fruitless search by him. Although Phillips says the species was abundant at Florence Court, Enniskillen, there is no specimen in the great collection of Lord Enniskellen, now also in the British Museum, which can be referred to it, nor have I been able to locate any other specimens among all the Irish collections. I have copied Phillips's figure of *P. egertoni* (fig. 14), which confirms the evidence of M'Coy's fragment as to the great number of brachials below the first bifurcation. The figure is palpably incorrect in the short, sharp-pointed arms, which doubtless had that appearance on account of being partly buried in the matrix, and having none of the ramules exposed; it represents a young specimen as compared with M'Coy's, which is drawn natural size.

This Irish species is remarkable for the great extension of the primary brachials, in which it is unique among the Flexibilia; and among the *Onychocrinus* type it stands alone in having ramules which apparently branch to the inside. The specimen is so imperfect, however, that we are not very certain as to the exact plan, and the intervals appear to be irregular. That it had an interbrachial system is shown, but this was evidently quite limited, and in this respect the affinities of the species would be rather with the *ramulosus* group.

*Types.* Science and Art Museum, Dublin, Ireland.

*Horizon and locality.* Middle part (Calp) of the Carboniferous limestone; Ballintrillick, Bundoran, County Donegal; also County Sligo, and Florence Court; Ireland. According to the lists of fossils given in M'Coy's Carboniferous Fossils of Ireland, pp. 238, 251, the stratigraphic position of this species is in the second, or Middle (Calp), of the three divisions into which he and other authors subdivide the Carboniferous limestone of England and Ireland. The first, or Lower, division is that known as the Lower Carboniferous, or Mountain limestone; and from it, and the so-called Carboniferous slates or shales below it, have been derived most of the Carboniferous species of crinoids and blastoids described by the British authors. These include such well known forms as *Amphoracrinus gilbertsoni, Actinocrinus triacontadactylus, Gilbertsocrinus calcaratus,* etc., which correspond with the crinoid fauna of the lower part of the American Lower Carboniferous, viz., the Burlington and earlier rocks. Therefore the present species must be assigned to a relatively later stage, whereby it will be comparable with those of the *ramulosus* group.

## INSERTAE SEDIS

The following genera, which have been referred by some authors to the Flexibilia, are of doubtful systematic position, or by reason of newly-acquired information can now be definitely shown not to belong to the group. It is therefore thought desirable for the sake of completeness, as well as to furnish a clear basis for future consideration of them by others, to indicate the present state of knowledge concerning them.

### **CLEIOCRINUS** Billings

*Cleiocrinus* Billings, Geol. Surv. Canada, Rep. Progress for 1853-56, 1857, p. 276.—Can. Organic Remains, Dec. IV, 1859, p. 52, fig. 17.—Bronn, Klass. u. Ord. Thier-Reichs, II, 1860, p. 232.—Shumard, Trans. Acad. Sci. St. Louis, II, 1866, p. 359.—Wachsmuth and Springer, Revision Palaeocrinoidea, pt. I, 1879, pp. 35, 147.—Revision Palaeocrinoidea, Pt. III, 1886, p. 152.—Zittel, Handbuch, Palaeontologie, I, 1879, p. 357.—Chapman, Classification of Crinoids, 1882, p. 2.—Miller, N. A. Geol. and Pal., 1889, p. 231.—Bather, Geol. Mag. (Dec. IV) V, July, 1898, p. 325.—Rep. Brit. Assoc. for 1898, 1899, p. 923.—Treatise on Zoology (Lankester), Pt. III, 1900, p. 191.—Geol. Mag. (Dec. V) II, May, 1905, pp. 231-233.—Springer, Amer. Geologist, XXX, 1902, p. 94.—Mem. Mus. Comp. Zool. Harvard, XXV, No. 2, 1905, pp. 93-114.—Geol. Surv. Canada, Mem. No. 15-P., 1911, pp. 41-44.—Wood, Bull. 64, U. S. Nat. Mus., 1909, p. 100.—Zittel-Eastman, Textb. Pal. I, 1913, p. 186 (Emend.).

*Genotype.* *Cleiocrinus regius* Billings.

*Distribution.* Lower Ordovician, Chazy and Trenton, Canada and the United States.

The structure, characters and systematic relations of this genus are fully exhibited and discussed in the author's papers of 1905, and 1911, viz.: Mem. Mus. Comp. Zool. Harvard, Vol. XXV, No. 2, 1905, pp. 93-114, pl. i, and Geol. Surv. Canada, Mem. No. 15-P, 1913, pp. 41-44, pl. 5, figs. 7-11*c*,—leading to the conclusion that it is an intermediate type. It has the flexible calyx and loose sutures of the Flexibilia, but its pinnulate arms and subtegminal mouth place it in closer relation with early Camerata, such as *Reteocrinus*. Its calycine pore-rhombs proclaim its not distant derivation from the Cystids. In the remarkable disposition of the basal and radial plates, in horizontal alternation instead of vertical succession, enclosing the infrabasals by their exterior surface instead of meeting their distal edge, this form differs from all other known Pelmatozoa. These intermediate and peculiar features accord with its very early age.

## **CALEIDOCRINUS** Waagen and Jahn

*Plates LXXV, fig. 9; LXXVI, fig. 24*

*Caleidocrinus* Waagen and Jahn in Barrande, Silur. Syst. Centr. Bohème, VII, pt. 2, 1899, pp. 106-112; text-figs. 27*a*-32, pl. 63.—Bather, Ann. and Mag. Nat. Hist. Ser. 7, Vol. VI, 1900, p. 111; Treatise on Zoology (Lankester), 1900, p. 202.—Springer, Jour. Geol. XIV, 1906, pp. 485-486.—Zittel, Grundz, Pal. I, 1910, p. 166.—Zittel-Eastman, Textb. Pal. Rev. Ed., Vol. I, 1913, p. 206.

Professors Waagen and Jahn proposed this genus in 1899 upon certain specimens occurring at Stage $d_4$ of the Second Fauna (Ordovician) of the Bohemian section, and placed it near the Taxocrinidae of Angelin. Bather [1] in reviewing their work the following year assigned this form to the Flexibilia Impinnata, considering it to be "a genus that approaches the common ancestor of *Ichthyocrinus* and *Taxocrinus*." Through the kindness of Professor Jahn, who made a special trip for me to the locality near Zahoran, I was able to secure several specimens of *C. multiramus* in as good condition as they are usually found. They occur in a schist, and the preservation is unfavorable to observation of some essential characters. The authors say of this [2]:

> The skeleton and elements constituting the body of these sea lilies are changed into a ferric hydrate. By reason of this change there exist only the negative impressions of half the calyx, which are filled with a powder of ferric hydrate.

They state in the explanations that the figures on their plate 63 are very defective ("idéalisées,"—"entièrement inexacte,"—"qui n'est pas conforme à la réalité"), and they give other figures in the text partly from the same and partly from better specimens. Even of these text-figures, however, they say on page 109:

> The preservation of the interradius (*ir*, figs. 27*b*-31*b* in the text), and of the anal interradius (*a*, figs. 27*b*-31*b* in the text), is so defective that if we can, in some cases, observe the position of the plates which compose them, it is never possible to determine their number.

I have six specimens in the condition described by the authors, viz., impressions in the matrix filled with powder of iron oxide; and one rather larger than usual in which, by rare good fortune, the calcareous skeleton of the crinoid is preserved intact. I have also wax casts of the specimens from which figures 1-2 and 11-14 on plate 63 of Waagen and Jahn's work were made, most courteously sent me by Professor Perner of the Royal Museum at Prague. In none of these have I been able to identify any interradial plates in the regular areas; and with reference to the text-figures of the authors, in which numerous small irregular plates are shown, I would suggest that in specimens preserved as these are it is impossible to determine such structures with certainty. Many foreign bodies, even fragments of arms, may become lodged between the rays which might, in the chemically changed condition of the fossils, be mistaken for small irregular plates. In my specimen with the external skeleton preserved (Pl. LXXV, fig. 9) the radial and brachial plates are well defined, and there is certainly no sign of any such plates meeting them between the rays.

Commenting in 1906 [3] upon the description of this genus by the Bohemian authors, and upon Bather's reference of it to the Flexibilia, I said:

> The habitus of this form seems to me rather like that of the Inadunata, from which it is separated only by the supposed interbrachial structures.

At that time nothing was known of the character of the anal side. Reëxamination of my specimens with further preparation has brought to light the structure of this part in the clearest manner, and furnishes the clue to the systematic position of the genus hitherto entirely overlooked by all authors. As is indicated in most of Waagen and Jahn's figures,

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[1] Annals and Magazine of Natural History, VI, 1900, p. 112.

[2] Barrande, Syst. Silur. Centr. Bohème, VII, 1899, p. 107.

[3] Jour. Geol. XIV, p. 486.

the primary plates of the rays consist of a radial and two or three primibrachs. It now further appears that the right posterior radial is a compound plate, the superradial being axillary, and supporting upon its left shoulder a series of plates which form the base of an anal tube or sac, thus giving precisely the structure of the Inadunate genus *Iocrinus*. This is definitely shown in two specimens, one of which is figured on Plate LXXVI, figure 24. Now that this is understood, we find the same thing in Waagen and Jahn's figure 14 on their plate 63, only the suture between the segments of the compound right posterior radial is not drawn. Consulting my figure 24 on Plate LXXV, it will be seen that the basals are well exposed, and the column obtusely pentagonal with the pentameres radial, indicating a monocyclic base. These characters, along with the large radials and dichotomous arms, leave nothing to separate the genus from *Iocrinus,* of which it is clearly a synonym. This conclusion is reinforced by the stratigraphic position of the fossils, the Ordovician Stage $d_4$ of Bohemia being correlated approximately with the American Trenton, in which *Iocrinus* occurs as an exceedingly strong and persistent type. It ranges with only slight modification of characters from the basal Trenton through the various Cincinnatian formations to the close of the Ordovician, and into the Richmond beds of the Silurian. It occurs as a part of a fauna which extends from the Cincinnati area through New York to Canada, and also in northern Illinois, associated with a fauna which Dr. Ulrich informs me represents a different migration. The latter occurrence shows greater differentiation of characters from the others than they do among themselves. With the vigorous and long-lived form indicated by this great time interval, it is not surprising to find its geographic range extending to the eastward of the Atlantic basin.

## **EDRIOCRINUS** Hall

*Plate LXXVI*

*Edriocrinus* Hall, Am. Jour. Sci. (Ser. 2), XXV, 1858, p. 278; Nat. Hist. New York, Pal. III, 1859, p. 119; 15th Rep. N. Y. St. Cab. N. H. 1862, p. 115 (sep. p. 87).—Meek and Worthen, Geol. Surv. Illinois, III, 1868, p. 370.—Schlueter, Zeitsch. Geol. Ges. XXX, 1878, p. 59.—Wachsmuth and Springer, Rev. Pal. I, 1879, p. 21; III, sec. 2, 1886, pp. 192, 262, 265; N. A. Crin. Cam. 1897, pp. 59, 145.—Chapman, Classification of Crinoids, 1882, p. 4.—Zittel, Handb. Pal. I, 1879, p. 350.—Zittel-Eastman, Textb. Pal. 1913, p. 206.—P. H. Carpenter, Ann. and Mag., May, 1883, p. 333.—Bather, Ann. and Mag. N. H. (6) V, Apr. 1890, p. 332, May, p. 379; Rep. Brit. Assoc. for 1898, [1899], p. 923; Treatise on Zool. (Lankester), pt. III, 1900, p. 191.—Walther, Zeitsch. Geol., Ges. 1897, p. 47.—Talbot, Am. Jour. Sci. (4) XX, 1905, p. 20.—Kirk, Eleutherozoic Pelmatozoa, Proc. U. S. Nat. Mus., vol. 41, 1911, pp. 111-114.—Springer, The Crinoid Genus *Scyphocrinus,* 1917, p. 11.

Crinoids without stem; either permanently attached directly by the base, or free in the adult stage. Monocyclic; BB 4, fused into a more or less hollow mass (hereinafter simply called the base) with sutures usually obliterated by secondary growth. RR in contact all around except at the anal side. Anal plate in line with radials, usually projecting above their level. Radial facets filling distal face of radials. Arms dichotomous. Pinnules probably wanting.

*Genotype. Edriocrinus pocilliformis* Hall.

*Distribution.* Lower Devonian, America.

A brief discussion of this genus is advisable for the reasons, first, that Bather in the Lankester Zoology, 1900, referred it provisionally to the Flexibilia Impinnata; and second, that I am now able to clear up certain structural points which have been in doubt, or obscured by erroneous interpretation. The latest formal diagnosis of the genus in 1905, reaffirmed as to species in 1913, declared it to be a dicyclic crinoid, with fused infrabasals and five basals,—all of which statements must now be corrected.

When proposing the genus in 1859[1] Hall defined the elements of the calyx as follows:

> Base solid, without division into plates: upper margin marked by six angles, with depressions between for insertion of radial plates. Radial plates five, inserted in the five larger depressions on the upper edge of the calyx. Anal plates two, the lower one inserted in the smaller of the six impressions (p. 119).

Based upon specimens of *E. sacculus* from the Oriskany of Maryland he stated that—

> These crinoids are sessile in the young state, adhering singly or in groups to other substances until fully developed, when they are separated from the foreign bodies, and, gradually secreting calcareous matter to cover the cicatrix or point of adhesion, become finally the smoothly rounded bases which we find so numerously (p. 120).

In the Revision of the Palaeocrinoidea, Pt. I, 1879, p. 21, Wachsmuth and Springer referred to the calyx of *Edriocrinus* as being attached when young, and in maturity becoming free; and in Pt. III, 1886, p. 262, we placed it provisionally under the Astylocrinidae along with other free-floating crinoids, saying that it " in all probability, forms a family by itself, being sessile in early life, and having no underbasals."

Bather in May, 1890,[2] listed *Edriocrinus* as a form which is " so extremely specialized . . . . that one cannot perceive its true affinities "; and in the Lankester Zoology, 1900, p. 191, he placed the genus provisionally in the Flexibilia Impinnata, giving the characters as follows:

> When young is attached by BB, but is free-floating in adult; BB become fused into a bowl-shaped mass, supporting 5 RR and *x*; arms broad, with low Br, isotomous.

Such was the state of opinion as to the characters of the genus until 1905, when Miss Mignon Talbot in a Revision of the New York Helderbergian Crinoids[3] proposed a new family for its reception, rejecting the systematic references of the genus by Wachsmuth and Springer and by Bather, saying as to the latter—

> Bather lists the genus provisionally under the order Flexibilia, an order with no anal plate in the cup(!); but as *Edriocrinus* has such a plate, the genus cannot be so referred (p. 22).

Her family diagnosis is in part as follows:

> Base dicyclic, probably 5 fused plates in each order . . . . attachment being by the infrabasals in the young stages; mature forms unattached.

In the course of a discussion of the characters of the genus, based chiefly upon specimens of *E. pocilliformis* from New York, some of which are figured upon the accompanying plate 4, figures 1-6, the author states that specimens No. 2 and No. 5, " instead of being monocyclic are dicyclic," and that " No. 3 shows infrabasals and basals " (p. 21). As the result of these observations she gives an amended diagnosis, of which the part material to the present inquiry reads as follows:

> *Amended generic description.*—Calyx directly cemented, either throughout life or only in the young stages, the attachment being by the large infrabasals. The cicatrix very large in some specimens and in others obliterated, by the accumulation of calcareous matter on the outer surface of the calyx plates. Infrabasals large, their height being from one-half to two-thirds that of the cup as ordinarily found, completely fused so as to destroy suture lines and to make the number of plates uncertain. Basals five, height varying in proportion to that of the infrabasals, generally so fused as to show no suture lines on the outer surface, although they are often seen on the inner side.

In conformity with this, the specific description which follows contains the same statements:—" Infrabasals present . . . . Basals five."

It is unfortunate that so material an addition as that of infrabasals and a definite number of basals to the characters given by all previous authors could not have been supported by more satisfactory evidence of the facts,—the more so since these statements have since been incorporated with the description of *E. pocilliformis* in the volume on the Lower Devonian, of the Reports of the Maryland Geological Survey, 1913, p. 257. Notwithstanding the definite statements above quoted as to certain specimens being dicyclic and showing infrabasals, I must say that the corresponding figures on plate 4 of the author's paper fail to show any means of determining the number of plates below the radials, or any indication of two rings of such plates, or in fact any structures essentially different from those shown by Hall's figures 8-12 on plate 5 of the New York Report, on which he based the statement in his description,—" base solid, without division of plates "; or those which I have seen in hundreds of specimens of the fused bases from New York, Maryland, Virginia and Tennessee. The raised collar on some specimens, which the author took to represent basals, distinguishable from the narrower mass below it thought to be infrabasals, is a mere irregular phase of secondary growth without definite structure, seen occasionally on specimens of different species. Also the lines seen at the inner surface of some of the fused bases are not interbasal sutures, as the author thought, but are lines or ridges marking the position of the superimposed radials and anal plate; they are always 6 in number, instead of 5 as they would be if dividing five basals (see Hall, *op. cit.*, pl. 5, fig. 12; pl. 87, fig. 14; and Pl. LXXVI, figs. 3, 16, 18 herein, in which both the ridges and the true suture lines are shown).

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[1] Nat. Hist. N. Y. Pal. III, 1859, pp. 119-121, 143.

[2] Ann. and Mag. N. H. (6) V, p. 379.

[3] Am. Journ. Sci. (4) XX, July, 1905, pp. 17-33, Plates I-IV.

Dr. Kirk, the latest author to discuss the characters of *Edriocrinus*,[1] follows substantially the definition of Hall, saying that—

> The cup consists of five radials and an anal plate . . . . This cup rests upon an apparently amorphous base (p. 112) . . . . This base for purposes of convenience I have styled a peduncle (p. 111).

As against these recent interpretations of the structure of the genus, I am now in position definitely to show by unquestionable evidence in four species that *Edriocrinus* is a monocyclic crinoid with 4 basals, as in *Melocrinus* and associated genera:

1. A rather small species, occurring only in the form of the fused basals somewhat abundantly in the Linden formation of the Helderbergian of western Tennessee, and in equivalent New Scotland beds of Virginia. As usually found in cherts or clay layers the specimens are silicified, and the rounded base is altered by secondary growth to an undifferentiated, more or less elongate, fused bulb, and all sutures at the surfaces are completely obliterated by growth or by silicification. Rarely the wall appears double, with an intermediate space that was filled with some fibrous matter now decomposed; and in one such specimen the original interbasal suture lines are marked by silicious partitions, by which the position of the 4 basals is distinctly shown (Pl. LXXVI, fig. 12). Defining species by means of the fused basals alone is rather unsatisfactory, as there is some variation among associated specimens; yet in the absence of better material this course seems advisable, in order to have names for some of the forms having rather characteristic facies as evidenced by the average form and proportions in a number of specimens. To this form I have given the name *Edriocrinus occidentalis* (Pl. LXXVI, figs. 6-12).

2. At a locality in the typical Linden limestone and shale beds in Perry County, Tennessee, a much smaller species occurs, in which the consolidated base is calcareous and the sutures are still visible, although sometimes partly obscured by growth, and indistinct or " ragged " at the surface. In such cases by grinding or scraping, the sutures can usually be found a short distance inward. I have nine specimens in which the sutures are perfectly plain, showing 4 basals in every case. This form, in which I first identified the 4 basals, may be called *Edriocrinus explicatus* (Pl. LXXVI, figs. 13-15).

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[1] Proc. U. S. Nat. Mus., vol. 41, 1911, pp. 112-114.

3. A remarkable species figured by Kirk under the name *Edriocrinus dispansus*,[1] also from the Linden formation of western Tennessee. For years there appeared rarely among Helderbergian collections from that area certain thick, broadly rounded, discoid bodies of apparently crinoidal nature, having a more or less indented depression on the undifferentiated rounded surface, while the opposite side is marked by both concentric lines of growth and radiating ridges (resembling those seen in *Apiocrinus;* De Loriol, Crinoids de la France, pl. 45, fig. *2a*),—the latter dividing that surface into five large triangular spaces, and a sixth about half as large. These disks proved to be the fused basals of a species of *Edriocrinus* of a habitus widely different from any before known, and the acquisition of several good specimens enables me to give a more complete description of the calyx. The radials are large, in form of triangles with truncate apex; they narrow to less than half their width from the proximal to the distal face, which is entirely filled by the arm facet. The anal plate, narrower and narrowing upward to a lesser degree, completes the circlet, which thus forms a low, truncated, obscurely hexagonal pyramid, contracting at the arm bases to less than half its diameter at the base (Pl. LXXVI, figs. 1, 2). The radiating ridges on the ventral side of the basal disk coincide in position with the interradial and radio-anal sutures, as if marking some kind of divisions at the bottom of the visceral cavity. The dorsal side of the disk is usually marked by a shallow concavity or an indented scar of much less than its own width, in which a small shell or other foreign object is sometimes still attached—showing that the base before becoming free often far outgrew its surface of attachment. No trace of arms has been seen; they must have been relatively small. The specimens range from 12 to 30 mm. width at the base, the calyx to the level of the arm bases being about one-half as high as wide, and its diameter at the apex about two-fifths that at the base. One of the detached basal disks (Pl. LXXVI, fig. 3) shows at the ventral side 4 perfectly distinct basal plates, the interbasal sutures being marked by lines of infiltrating matter of different color from that of the plates. The extreme contraction of the calyx at the arm bases is a striking character of this species, and is at variance with the structure of the Crinoidea generally.

There is another small form in the Linden formation of western Tennessee that is always broadly attached by the fused base. It occurs sparingly at the same locality with *E. dispansus,* and at localities along the Tennessee River, adhering to shells larger than itself, and especially to the bulbous roots of *Scyphocrinus* (*Camarocrinus*). Only the fused bases have been seen, which are rather thin and delicate, tending to spread out upon the contact surface to a width exceeding their diameter at the distal face, instead of being rounded as if to become free. The specimens range from 5 to 10 mm. in diameter. Radiating ridges appear on the ventral surface as in *E. dispansus,* indicating a rather mature stage of growth, and also the possibility that this form had a similar pyramidal calyx. It may be the young stage of that species, or may represent a distinct species bearing the same relation to it as *E. holopoides* to *E. sacculus.* Adopting the latter view, it may take the name *Edriocrinus adhaerens* (Pl. LXXVI, figs. 16-18).

4. As originally stated by Hall, it has been generally assumed by authors that *Edriocrinus* was sessile in the young stage, but became free when adult. The acquisition of a large quantity of unusually fine material from the Oriskany formation in the typical locality for *E. sacculus* at Cumberland, Maryland, enables me to throw some light on this question also. The occurrence at Cumberland is the only one in which this crinoid has been found with the arms complete. The prevalent form, hitherto identified only as *E. sacculus,* attains a much larger size than those of other localities, and the fused basals of the free floating stage are found by the hundreds. With few exceptions these expand toward the radials in the form of an inverted cone, rounded and rather narrow at the lower extremity, the upper edge more or less oblique to the vertical axis. The wall is double, enclosing a space which was evidently occupied by fibrous or porous structures; the inner surface is often marked by

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[1] Proc. U. S. Nat. Mus., vol. 41, 1911, p. 112, pl. 11, figs. 1, 2.

peculiar lines of growth. Doubtless when very young these were all attached to other objects by the lower ends of the basals, which were obscured in the process of attachment, and when free became totally changed by secondary growth, in which condition all signs of suture lines are obliterated. Many small specimens are found attached to hard objects, either singly or in clusters, sometimes half a dozen on a single shell. Various forms of these bases are shown by Hall's figures in Volume III, Pal. N. Y. plate 87.

But along with these are a considerable number ranging from small to full adult size which have a broad, flat, encrusting base for fixation, wonderfully like the mode of attachment of the existing genus *Holopus*. Specimens of this class have a different aspect otherwise from those with rounded base, and upon assembling the material it became evident that the two types are specifically distinct, the attached form having uniformly much shorter rays. Excluding the very young individuals, in which the primary brachials cannot be counted because they infold before the first bifurcation, there are 63 specimens from small to maximum size with one or more of the rays preserved, many of them entirely complete; of these 42 are free as figured by Hall on plate 87, figure 10, and all of them agree with his description of *E. sacculus* in having 10 or 12 (or more) very short primibrachs. Of the other 21 specimens with attached base, 16 have 5 IBr in nearly all the rays, and the remaining five have from 5 to 7. Several sessile specimens have 10 IBr, but they are all small ones which might have become free with age. Thus without exception in the adult the sessile form has 5 (or at the most 6 or 7) IBr, and the free floaters 10 or more,—a constancy of characters quite sufficient to separate the species. There are numerous detached bases of the sessile form, which differ markedly from the others by their much thinner walls and broader cavity. Both forms are well illustrated on plate 40 of the volume on the Lower Devonian, of the Maryland Geological Survey, 1913, of which figures 10, 11, 12 show the free form, *E. sacculus,* with its 10 or more IBr, while figures 7, 8, 9 represent the sessile form with 5 IBr, for which I propose the name *Edriocrinus holopoides.* The original of figures 7-9, which I have refigured as the type specimen (Pl. LXXVI, figs. *22a, b*), is in an unusually good state of preservation, the attachment having been to a smooth object; and it distinctly shows upon the lower surface of the encrusting base the course of the original suture lines of the 4 basal plates, as appears by the photographic figure, *22b.*

Both of these forms have the same large anal plate; very broad arms, branching, and strongly curving distally, with a distinct, rather large ventral furrow or food groove. The preservation in the coarse sandstone matrix has been impaired by chemical action due to the presence of iron oxide, so that finer structures are obscured; thus we do not know how the food groove was covered, nor whether pinnules were present. There might have been short, stout appendages as in *Holopus,* but no evidence of them is visible in the fossils.

The outstanding fact in regard to this singular form is the complete absence of a stem, and its remarkable superficial resemblance to *Holopus,* from which it differs broadly in its bilateral symmetry due to the presence of the large anal plate, and in the probable absence of pinnules. Both are of a littoral or circum-littoral habitat. *Holopus* occurs on rocks or corals within a few fathoms depth, while the Oriskany sandstone in which the largest species of *Edriocrinus* occur is recognized as a littoral deposit. The time interval between them is a tremendous one, perhaps partially bridged by *Eugeniacrinus* and its congeners from the Jurassic to the Cretaceous, and by *Cyathidium* from Cretaceous to Tertiary. The two doubtless represent parallel modifications of independent stocks, resulting from their encounter with similar physical conditions. There is no evident connection between *Edriocrinus* and any other Devonian or pre-Devonian form, unless the newly discovered fact of the 4 basals may suggest some remote relation to the *Melocrinidea.* The monocyclic base and rigid construction of the calyx are facts which negative a connection with the Flexibilia as now limited.

Kirk (*op. cit.*, p. 113) disagrees with the provisional reference of the genus to the Flexibilia, but does not undertake to determine its relations.

P. H. Carpenter, in the Challenger Report on the Stalked Crinoids, page 211 *et seq.*, discussed the systematic position of *Holopus,* which he placed in the family Holopidae, including *Eudesicrinus, Cyathidium,* and *Cotylecrinus;* and in that connection he stated that *Edriocrinus* is "very closely allied to the recent *Holopus* and to *Cotylecrinus*"—differing from them only in the presence of the anal plate, which difference, as pointed out by Meek and Worthen, is the same as between *Hexacrinus* and *Platycrinus.* These two genera, however, he says "are both Paleocrinoids; but *Belemnocrinus* and *Rhizocrinus,* a Paleocrinoid and a Neocrinoid respectively, are related in precisely the same way."

Mr. Austin H. Clark does not think it possible that *Edriocrinus* can be closely related to *Holopus.* In a recent paper[1] he expresses the opinion that "the pentacrinites, the comatulids and *Holopus* are very closely related, in spite of their extraordinary superficial dissimilarity."

The geological range of *Edriocrinus* is restricted to the Helderbergian and Oriskany of the Lower Devonian, and it is not certainly known outside of America, although Jaekel thinks *Lodanella mira* Kayser may belong to it. The new species indicated in the foregoing remarks added to those heretofore described make a total of nine, two of which are represented by the complete crown, three by the calyx, and four by the fused base only. Diagnoses of them all, in addition to that of the genus already given, in view of the new information now obtained, may be stated as follows:

## Section I

*Free in the adult stage, with fused basals rounded below.*

### **Edriocrinus pocilliformis** Hall

*Edriocrinus pocilliformis* Hall, Nat. Hist. N. Y. Pal. III, 1859, p. 121, Pl. V, figs. 8-12.—Meek and Worthen, Geol. Sur. Illinois III, 1868, p. 370, Pl. VII, figs. 5*a*, *b*.—Wachsmuth and Springer, Rev. Pal. III, Sec. 2, p. 266.—Keyes, Geol. Surv. Missouri, IV, 1894, p. 221, Pl. XXX, fig. 7.—Talbot, Am. Jour. Sci. (4) XX, 1905, p. 23, pl. 4, figs. 1-6.—Maryland Geol. Surv. Lower Devonian, 1913, p. 257, Pl. XL, figs. 13-15.

Type of the genus.

A small species, known only by the calyx. Base small, low hemispheric, broadly convex, expanding upward; height to width about as 1 to 1.3; specimens ranging in size from 4 to 15 mm. high and 7 to 20 mm. wide at basiradial suture. Radial circlet cylindrical, longer than wide, and slightly longer than the base; anal plate narrower than radials. Traces of a narrow indented scar are occasionally seen on the rounded base, and radiating ridges on the ventral surface.

*Type.* American Museum Natural History, New York.

*Horizon and locality.* Helderbergian, New Scotland formation, Albany County, New York; Perry County, Missouri.

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[1] The systematic position of the crinoid genus *Holopus,* Jour. Washington Academy of Sciences, March, 1919, vol. 9, pp. 136-138.

### **Edriocrinus occidentalis** n. sp.

*Pl. LXXVI, figs. 6-12*

A rather small species, known by the base only. Base small, elongate, broadly rounded at lower end, with thick wall enclosing an inversely conical tubular cavity which narrows downward, leaving the wall thickest at the lower part; often constricted below the radial facet and expanding again towards them. Height to width in average of 20 specimens showing all variations, about as 1 to .75; specimens varying in size from 8 to 20 mm. high, and from 6 to 14 mm. wide at top.

*Types.* In the author's collection.

*Horizon and locality.* Helderbergian, Linden formation; in cherts and clay bands, in Stewart and Decatur counties, Tennessee, and in the equivalent New Scotland formation in Allegheny County, Virginia. This is the species of *Edriocrinus* mentioned by Dr. Foerste in Journal of Geology VII, 1903, pp. 682-7, as occurring "near the western end of the exposures along the Cumberland River, west of Cumberland City," which he was inclined to refer to the Camden chert. Dr. Bassler, who has since carefully reviewed the stratigraphy of that region, informs me that the Cumberland River exposures in question may be properly included in the Linden. The correlation as above given of the beds on the east flank of the Appalachian Mountains near Covington, Virginia, is upon the authority of Dr. Ulrich, who assures me that the occurrence of the same species in the two areas might well be expected.

### **Edriocrinus explicatus** n. sp.

*Plate LXXVI, figs. 13-15*

A smaller form than the last one, known from the base only. Base subglobose, widening slightly upward, with basals but slightly modified by secondary growth and the sutures therefore observable. Height and width about equal, and specimens varying from 5 to 9 mm. each way.

*Types.* In the author's collection.

*Horizon and locality.* Helderbergian, Linden formation, Perry County, Tennessee.

### **Edriocrinus dispansus** Kirk

*Plate LXXVI, figs. 1-5*

*Edriocrinus dispansus* Kirk, Proc. U. S. Nat. Mus., vol. 41, 1911, p. 112, pl. 11, figs. 1, 2.

A medium-sized species, known only by the calyx. Base low, discoid, usually with remnant of indented scar of attachment at younger stage. Calyx with radials in position in form of an obscurely hexagonal, truncated pyramid, contracted at the top of the radials to less than half its diameter at the base. RR narrowing upward to short distal faces. Anal plate long, narrow, projecting in an angular apex above the line of radials. Height of base about one-tenth its width; height to width of calyx about 1 to 1.8, varying in eight specimens from 6 to 15 mm. high and 12 to 30 mm. wide at the base; width of calyx at base two and a half times its diameter at the radial facets, where it ranges from 7 to 10 mm. Parts above radials not known.

*Types.* Kirk's original is in the U. S. National Museum; the other specimens figured are in the author's collection.

*Horizon and locality.* Helderbergian, Linden formation, Benton County, Tennessee.

### **Edriocrinus sacculus** Hall

*Edriocrinus sacculus* Hall, Nat. Hist. N. Y. Pal. III, 1859, p. 143, pl. 62, figs. 8, 9; pl. 87, figs. 1-22.—Ohern, Geol. Surv. Maryland, Lower Devonian, 1913, p. 256, Pl. XL, figs. 10, 11, 12.—Weller, Geol. Surv. N. J. Pal. III, 1903, p. 342, Pl. XLV, figs. 3-5.—Kirk, Proc. U. S. Nat. Mus. 41, 1911, p. 112, pl. 11, figs. 14, 15.—Jaekel, Palaeont-Zeitschr. Bd. 1, 1914, p. 383.

The largest species; represented by the complete crown. Base inverted conical, usually asymmetric with the upper edge oblique, broadly spreading from a narrow rounded apex, enclosing a large cavity of similar form; walls thick, double, with space for fibrous structures between. Radial circlet cylindrical; RR rectangular, enclosing wide anal plate projecting above them between arm bases. Arms broad and flat, with well defined food-groove; dichotomous, branching two or three times, curving outward and distal ends closely inrolled, forming a rounded cluster exceeding the calyx in diameter. IBr 10 to 12, occasionally more; short, transversely linear, with beveled sutures. Height to width of base in average of 40 large and small specimens, about 1 to 1. Maximum crown from rounded base to top of recurved arms 65 mm. high and 40 mm. wide at greatest width of arm cluster; calyx at arm bases, 44 mm. high by 28 mm. wide; base, 27 by 26; maximum free base, 42 mm. high by 35 mm. wide; minimum free base 10 mm. high by 12 mm. wide. Still smaller specimens occur attached to other objects singly or in clusters having about 10 IBr as in this species.

Jaekel,[1] under the name *Lodanella mira* Kayser, from the Lower Devonian sandstone, Singhofen an der Lahn, figures fragments of a specimen which he compares with *Edriocrinus sacculus;* figure 1 is a restoration of the calyx and arms, largely modeled on Hall's figures. The horizon is comparable with the Oriskany sandstone, and the author notes the relationship of a faunal element of the American and Rheinish Devonian. He thinks the affinities of this form are with the Flexibilia.

Schlueter[2] mentions a species described by Hall in the Palaeontology of New York, Tom. 3, as *"Edriocrinus spiralis,"*—probably intending to cite this species.

*Types.* Hall's original in American Museum of Natural History, New York; those figured by Kirk in the U. S. National Museum.

*Horizon and locality.* Oriskany sandstone, Cumberland, Maryland.

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[1] Palaeont. Zeitschr. Bd. 1, 1914, p. 483, figs. 1-4.

[2] Zeitschr. Geol. Gesell. XXX, 1878, p. 59.

### **Edriocrinus becraftensis,** J. M. Clarke

*Edriocrinus becraftensis* Clarke, Mem. III, New York State Museum, 1900, p. 62, pl. 9, figs. 12, 13.

A rather large species, known by the base only. Base very elongate, narrowly conical, slightly widening upward. Height to width about 1 to .75; type specimen 30 mm. high, 15 mm. wide at upper end, and 8 mm. near the lower rounded extremity.

*Type.* New York State Museum, Albany.

*Horizon and locality.* Oriskany sandstone, Becraft Mountain, Columbia County, New York.

## SECTION II

*Attached through life by encrusting base adapted to the form of objects to which attached.*

### **Edriocrinus adhaerens** n. sp.

*Plate LXXVI, figs. 16-18*

A very small species; only the fused base known. Base low, spreading more or less at the encrusting surface, enclosing a broad shallow cavity; wall thin. Height to width of base about as 1 to 2. Specimens ranging from 5 to 10 mm. in diameter. Maximum specimens are nearly as wide as minimum specimens of *E. dispansus* having the rounded base fully developed, thus making it improbable that this is the young stage of that species.

*Types.* In the author's collection.

*Horizon and locality.* Helderbergian, Linden formation, Hardin and Benton counties, Tennessee. Usually found attached to shells or *Camarocrinus* bulbs.

### **Edriocrinus pyriformis** Hall

*Plate LXXVI, figs. 19-21*

*Edriocrinus pyriformis* Hall, 15th Rep. New York State Cab. Nat. Hist. 1862, p. 115 (sep. p. 87), text-figs. 1 and 2.—Kirk, Proc. U. S. Nat. Mus. 41, 1911, p. 112, pl. 11, fig. 9.

A medium-sized species, known only by the calyx. Base elongate, cylindrical, with concave scar for attachment. RR long, expanding upward, giving a turbinate aspect to the radial circlet; contracting toward the upper margin which is more or less abruptly bent in, so that the diameter at the radial facets is considerably less than that of the expanded portion below. Anal plate narrow, projecting above radials.

Hall's figures 1 and 2, on page 111 (87) of the 15th Report were drawn from three specimens,—figure 1 being a composite based upon a flattened calyx and two perfectly rotund sets of radials, and figure 2 a distal view of one of the latter. They show the form and proportions of the species with entire accuracy. Measurements of six specimens give the following average dimensions: Height of calyx, 33 mm., of radials, 18 mm., of base, 15 mm.; width at zone of greatest expansion, 18 mm., contracting to 13 mm. at radial facets; at basi-radial suture 10 mm.; base at surface of attachment, 10 mm. The extremes depart but little from this mean. This species is not quite constant in the sessile base, as among six specimens with base preserved, five have a broad concave scar, one has the scar almost completely overgrown; while a seventh, detached base only, associated with the others, is rounded.

*Type.* In American Museum of Natural History, New York.

*Horizon and locality.* Helderbergian, Oneida County, New York. In Hall's description the horizon is erroneously given as Upper Helderberg, and the locality as Eastman's quarry, south of Utica, New York; and my own specimens, originally in the Lyon collection and obtained by exchange from Hall, are similarly labeled. Eastman's quarry, as known at the time when these specimens were collected, was located ten or twelve miles southeast of Utica, in the region of Litchfield, where the Coeymans limestone of the Helderbergian is well developed and has yielded important collections of fossils lithologically similar to these.

### **Edriocrinus holopoides** n. sp.

*Plate LXXVI, figs. 22a-b, 23*

*Edriocrinus sacculus,* in part, Ohern, Geol. Surv. Maryland, Lower Devonian, 1913, pl. 40, figs. 7, 8, 9 only.

A large species, but smaller than *E. sacculus,* and with a shorter base; represented by the complete crown. Base low and broad, usually standing oblique to the surface of attachment; wall thin, enclosing a broad, bowl-shaped cavity not contracting downwards; expanding slightly towards the radials. Calyx and arms otherwise similar to these of *E. sacculus,* except that the arms are shorter and their inrolled cluster relatively not so wide. IBr 5 or 6, exceptionally 7 or 8. Height to width of base in average of 21 large and small specimens, about 1 to 1.25. Dimensions of maximum crown: 45 mm. high and 35 mm. wide at greatest expansion of arm cluster; calyx, 28 mm. high by 25 mm. wide at the arm bases; base, 17 mm. high by 19 wide; minimum crown, 8 mm. high by 7 mm. wide; minimum base, 4 mm. high by 6 mm. wide. Thus up to their maximum the specimens of this species range in size about like those of *E. sacculus,* but the latter becomes considerably larger.

*Type.* The specimen figured in the Maryland Report, formerly belonging to Mr. Hartly, is now in the author's collection.

*Horizon and locality.* Oriskany sandstone, Cumberland, Maryland.

## **RHOPALOCRINUS** Wachsmuth and Springer

*Plate LXXV, figs. 11a-d*

*Rhopalocrinus* Wachsmuth and Springer, Revision Palaeocrinoidea, pt. 1, 1879, p. 57; *ibid.*, pt. 3, Sec. 2, 1886, p. 176.—Bather, Rep. Brit. Assn. for 1888, 1899, p. 923; Lankester's Treatise on Zool., pt. 3, 1900, p. 191.—Springer, Amer. Geol. XXX, 1902, p. 95; Jour. Geol. XIV, 1906, p. 484.—Zittel-Eastman, Textb. Pal. 1913, I, p. 206.

*Genotype.* *Taxocrinus gracilis* Schultze (not *Taxocrinus gracilis* Meek and Worthen), Monogr. Echinod. Eifel Kalkes, 1866, p. 37, pl. 4, figs. 3, 3*a*.

*Distribution.* Middle Devonian, Eifel, Germany.

In proposing this genus under the family Ichthyocrinidae for the species which Schultze had described under the name *Taxocrinus gracilis,* Wachsmuth and Springer pointed out its close relationship in arm structure and in the possession of an elongate ventral tube to such genera as *Synbathocrinus,* and expressed doubt whether it belongs to the *Ichthyocrinidae,* which family as then conceived embraced all the Flexible crinoids. In the revised edition (1913) of Zittel-Eastman's Textbook of Palaeontology, page 206, it is stated that this form "might be described as a dicyclic Synbathocrinoid, with some interbrachial plates." This characterization was induced largely by the presence of the strong ventral tube, apparently extending to the full height of the arms. This fact was not shown by Schultze's figures, but I have been enabled by some further preparation of the type specimen, now in the Museum of Comparative Zoology at Harvard, to illustrate the actual structure in this respect very clearly, as shown by figures 11*b, c* on Plate XXV. The interbrachials (fig. 11*d*), the presence of which is contrary to the dominant character of the typical Inadunata, bear considerable resemblance to those found in some primitive Inadunates like *Cupulocrinus,* as shown upon the same plate, figures 2*a,* 5; they are irregular and may be only sporadic, as they occur in but a single interradius.

But for the tube, the affinities of the genus would be decidedly with *Cupressocrinus,* which it strongly resembles in shape and formation of the arms, especially in the presence of the very short first brachial, which is a marked character in all the species of that genus. The two genera are similar in having a dicyclic base, of which in *Rhopalocrinus* the lower ring is represented by an undivided disk as in *Cupressocrinus.* Schultze's figure 3, showing a suture directly below the posterial basal, is incorrect, as is my copy of it at figure 11*a,* in which the error was inadvertently preserved. In this respect the statement of Wachsmuth and Springer (Revision Palaeocr. pt. 1, p. 58), that this form has "underbasals 3," must also be corrected. Unfortunately but a single specimen of the type species has ever been found, and we do not know to what extent the singularly composite characters which it presents are persistent.

On account of the massive tube, which as now disclosed by the new figures represents an extension of a tegmen composed of solid plates, this genus must be excluded from the Flexibilia. As to this character it belongs rather to the Fistulate Inadunata.

## **CYDONOCRINUS** Bather

## **SYCOCRINUS** Austin

Dr. Bather in 1913[1] described a new genus, *Cydonocrinus,* and in 1914[2] redescribed Austin's hitherto imperfectly known *Sycocrinus,* both from the upper Visean zone of the British Lower Carboniferous. To the latter genus he refers the species *Hypocrinus pyriformis* Rothpletz, from the island of Timor; and he ranges the two genera under the Taxocrinidea for reasons given in his very full discussion of their characters. I have not seen any of the specimens (the single one in the Austin collection not having been observed by me when I examined that collection), but Dr. Bather's descriptions and figures leave nothing to be desired.

These forms are remarkable for the position of the anus, which opens laterally directly through the dorsal cup and below the level of the radials, as in the Gasterocomidae. All have three large infrabasals, of which the small plate is in the right posterior position. The dorsal cup is globose or ovoid, strongly constructed, contracting at the arm bases to a narrow tegmen, with no indication of any incorporation of brachials within it, either by lateral union or by solid or perisomic interbrachial structures; nor does there seem to be any place where such structures might have rested. The shape of the radial facets indicates that the rounded arms were free from their origin on the radials; and one gets the same impression from both Bather's and Austin's reconstruction of *Sycocrinus* (*op. cit.,* 1914, Pl. X, figs. 1*d* and 2*e*). The tegmen is not known, but the space for it is greatly reduced, and the construction at the margin indicates that it must have been rigid, probably like that of the Cyathocrinidae. The only character which these specimens have in common with the Flexibilia is the right posterior position of the small infrabasal. The position of this plate is not constant, neither in the Flexibilia nor in the Inadunata. In the former it is usually right posterior, but in some species of *Forbesiocrinus,* as elsewhere shown, it is anterior. In *Gissocrinus* of the latter, as shown by Bather in The Crinoidea of Gotland, it is extremely irregular. In *Hypocrinus,* from which he separates *H. pyriformis* chiefly on this character, the small IB is anterior. But in *Lecythiocrinus,* from the American upper Carboniferous, which specimens acquired since the original description show to have not only the same type of anal opening, but also three infrabasals, the small plate is right posterior. In the Inadunate family Gasterocomidae the infrabasals are unstable, often fused to 3 or 1—most frequently the latter according to my observation.

The entire facies of these forms is opposed to that of the Flexibilia, and in every respect where they differ from that group they agree with the Inadunata. The dorsal position of the anus is unknown among the Flexibilia. While it is true, as Bather suggests, that this does not preclude the discovery of such a form, yet when there is within the Inadunata such a family as the Gasterocomidae, which will receive forms like this without violating fundamental conceptions, I must be pardoned for not being able to perceive sufficient reason for referring them to the Flexibilia, with whose leading characters, according to my conception of them, they are in nearly every respect in conflict.

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[1] Ann. and Mag. Nat. Hist. 1913, p. 388.

[2] *Ibid.,* 1914, p. 252.

# BIBLIOGRAPHY

Including the Works Referred to in This Monograph, Arranged Alphabetically by Authors and Chronologically Under Each Author

Agassiz, Alexander.

1888. Three Cruises of the United States Coast and Geodetic Steamer "Blake" from 1877 to 1880. 1888, vol. 1, xxii and 313 pp., 194 text-figs., map; vol. 2, 220 pp., figs. 195-545. Cambridge, Mass.

1892. Calamocrinus Diomediae, a New Stalked Crinoid, with notes on the apical system and the homologies of Echinoderms. Mem. Museum Comp. Zoology, Harvard College, vol. xvii, no. 2, 1892, 95 pp., 32 pls. Cambridge, Mass.

Agassiz, J. L. R.

1836. Prodrome d'une monographie des radiaires ou echinodermes. Mém. Soc. Sci. Nat. Neuchatel, vol. i, 1836, pp. 168-199. Neuchatel.

Angelin, N. P.

1878. Iconographia Crinoideorum in Stratis Sueciae Siluricis Fossilium. 1878, 4to, iv and 62 pp., xxix pls. Holmiae.

Austin, Thomas, Esq., and Austin, Thomas, Jun.

1842. Proposed Arrangement of the Echinodermata, particularly as regards the Crinoidea, and a Subdivision of the Class Adelostella (Echinidae). Ann. & Mag. Nat. Hist. (1), x, 1842 (Oct.), pp. 106-113. London.

1843. Description of Several New Genera and Species of Crinoidea. Ann. & Mag. Nat. Hist., (1), xi, 1843 (March), pp. 195-207. London.

1843-1849. Monograph on Recent and Fossil Crinoidea, with figures and descriptions of some recent and fossil allied genera, parts 1-8. 1843-49, 4to, 128 pp., xvi pls. London and Bristol.

Baily, W. H.

1875. Figures of Characteristic British Fossils, with descriptive remarks, vol. i, Palaeozoic, 1867, 1869, 1871, 1875, 8vo, lxxx and 126 pp., xlii pls., 18 text-figs. London.

Barrois, Charles.

1889. Faune du Calcaire d'Erbray (Loire Inférieure), Contribution a l'étude du Terrain Dévonien de l'Ouest de la France. Mém. Soc. géol. du Nord, tome iii, 1889 (Avril), 348 pp., xvii pls. Lille.

Bather, F. A.

1890. British Fossil Crinoids. II. The Classification of the Inadunata Fistulata. Ann. & Mag. Nat. Hist. (6), v, 1890 (April, May, June), pp. 310-334, 373-388, 485, 486, pls. xiv, xv.

1892. British Fossil Crinoids. VI. *Botryocrinus quinquelobus*, sp. nov., Wenlock limestone, and note on *B. pinnulatus*. Ann. & Mag. Nat. Hist. (6) ix, 1892 (March), pp. 189-194, pl. xi, 3 text-figs.

1892. British Fossil Crinoids. VII. *Mastigocrinus loreus*, nov. gen. et sp., Wenlock limestone, Dudley. Ann. & Mag. Nat. Hist. (6), ix, 1892 (March), pp. 194-202, pls. xi, xii, 10 text-figs.

1892. British Fossil Crinoids. VIII. *Cyathocrinus: C. acinotubus*, Ang. and *C. vallatus*, sp. nov., Wenlock limestone. Ann. & Mag. Nat. Hist. (6), ix, 1892 (March), pp. 202-226, pl. xiii, 7 text-figs.

1892. The Fossil Crinoidea in the British Museum. An attempt to put into practice modern ideas of museum arrangement. Ann. Rep. Mus. Assoc. for 1891, 1892 (June), pp. 78-110.

1893. The Crinoidea of Gotland. Part I, The Crinoidea Inadunata. Kongl. Svenska Vet.-Akad., Handl. xxv, no. 2, 1893 (November), 180 pp., x pls., and 20 text-figs.

1896. On Uintacrinus. A morphological study. Proc. Zool. Soc. London for 1895, 1896 (April), pp. 974-1004, pls. liv-lvi, 13 text-figs.

1898. Wachsmuth and Springer's Classification of Crinoids. Natural Science, xii, 1898 (May), pp. 337-345.

1898-99. Wachsmuth and Springer's Monograph on Crinoids. Geol. Mag. (n. s.) dec. iv, vol. v, 1898 (June, July, September, November) and 1899 (January, March), pp. 276-283, 318-329, 419-428, 522-527, and vol. vi, pp. 32-44, and 117-127, with 34 text-figs. Also issued separately, with an obituary notice and portrait of Charles Wachsmuth, a list of the published scientific writings of Charles Wachsmuth, and an index to the review. London, April, 1899.

1899. A Phylogenetic Classification of the Pelmatozoa. Rep. 68th Meet. Brit. Assoc. Adv. Sci. Bristol, 1898, 1899 (Feb.), pp. 916-923.

1900. A Treatise of Zoology, edited by E. Ray Lankester. Part III, The Echinoderma. (Chaps. viii-xii by F. A. B.) 1900 (March), 8vo, viii and 344 pp., 309 text-figs. London.

1900. The Lower Palaeozoic Crinoids of Bohemia (review of vol. vii, pt. 2, of Barrande's "Systeme Silurien du Centre de la Boheme, lere partie: Recherches Paléontologiques," by W. Waagen and J. J. Jahn). Ann. & Mag. Nat. Hist. (7), vi, 1900 (July), pp. 102-121, 7 text-figs.

1901. Silurian Crinoids of Chicago (review of "The Paleontology of the Niagaran limestone in the Chicago area. The Crinoidea," by Stuart Weller). Geol. Mag. (n. s.) dec. iv, vol. viii, 1901 (August), pp. 376-379.

1905. Cleiocrinus by Frank Springer (a review). Geol. Mag. (n. s.) dec. 5, vol. 2, May, 1905, pp. 231-233.

1913. British Fossil Crinoids. IX. Cydonocrinus parvulus, n. g., et sp., *Yoredale Beds, Yorkshire.* Ann. & Mag. Nat. Hist. (8), xii, 1913 (October), pp. 388-394, 5 text-figs.

1914. British Fossil Crinoids. X. Sycocrinus Austin, Lower Carboniferous. Ann. & Mag. Nat. Hist., ser. 8, vol. xiii, 1914 (Feb.), pp. 245-255, pl. 10.

Beede, J. W.

1906. Fauna of the Salem Limestone of Indiana, Echinoderma. Thirtieth Ann. Rep. Dept. Geol. & Nat. Res. of Indiana for 1905, 1906, pp. 1243-1270, pls. vii, xii-xviiA, xix, xxvi, text-figs. 4, 5. Indianapolis.

Beyrich, H. E.

1871. Ueber die Basis der Crinoidea Brachiata. Monatsber. Akad. Wiss. Berlin, pp. 33-55, 13 text-figs. Translation in Ann. & Mag. Nat. Hist. (4), xi, 1871 (June), pp. 393-411, 13 text-figs.

Billings, Elkanah.

1856. Fossils of the Upper Silurian Rocks, Niagara and Clinton Groups. Canadian Nat. & Geol., vol. 1, no. 1, art. vi, 1856 (Feb.), pp. 57-60, 1 pl. Ottawa.

1857. New Species of Fossils from the Silurian Rocks of Canada. Geological Survey of Canada. Report of progress for the years 1853-1856; report of the palaentologist for 1856, 1857, pp. 256-345. Toronto.

1859. On the Crinoidea of the Lower Silurian Rocks of Canada. Geological Survey of Canada. Canadian Organic Remains, dec. iv, 1859 (June 1), pp. v, vi and 7-66, 10 pls., 18 text-figs. Montreal.

Bronn, H. G.

1843. Paläontologische Collectaneen. Neuen Jahrbuch für Min. Geol. Geogn. und Petrf. Jahrgänge [1840-1843], 1843, 156 pp. Stuttgart.

1848. Index Palaeontologicus oder Uebersicht der bis jetzt bekannten fossilen Organismen. 8vo, 1. Abtheil, A. Nomenclator palaeontologicus, lxxxiv and 1382 pp., 1848.

1849. 2. Abtheil, B. Enumerator palaeontologicus, 976 pp., 1849.

Bronn, H. G., and Roemer, F.

1851-6. Lethaea Geognostica oder Abbildung und Beschreibung der für die Gebirgs-formationen bezeichnendsten Versteinerungen. Vol. i, 8vo, pts. 1 (Bronn), 2 (Roemer), v-xii, and 788 pp., 1851-1856. Atlas, 4to, 124 pls. Stuttgart.

1860. Die Klassen und Ordnungen des Thierreichs, wissenschaftlich dargestellt in Wort und Bild. Zweiter Band, der Strahlenthiere (Actinozoa). 1860, 434 pp., 48 pls. Leipzig und Heidelberg.

Bury, H.

1888. The Early Stages in the Development of Antedon Rosacea. Phil. Trans. Royal Soc., vol. 179 (1888), B, 1888, pp. 257-301, pls. 43-47. London.

Calvin, S.

1883. On the Fauna Found at Lime Creek, Iowa, and Its Relation to Other Geological Faunas. American Jour. Sci. & Arts, vol. 25, 1883 (June), pp. 432-436. New York.

Carpenter, Phillip Herbert.

1883. On the Supposed Absence of Basals in the Eugeniacrinidae and in Certain Other Neocrinoids. Ann. & Mag. Nat. Hist. (5), xi, May, 1883, pp. 327-334.

1884. Report on the Crinoidea Collected During the Voyage of H. M. S. Challenger, During the Years 1873-1876—The Stalked Crinoids. Report on the Scientific Results of the Voyage of H. M. S. Challenger during the Years 1873-76. Zoology, vol. xi, pt. xxxiii, 1884, x and 442 pp., 68 pls. (in i-lxii), 21 text-figs., 10 tables.

1884. On a New Crinoid from the Southern Sea. Phil. Trans. Royal Soc., clxxiv, for 1883, 1884, pp. 919-933, pl. lxxi. London.

CARPENTER, WILLIAM B.

1866. Researches on the Structure, Physiology, and Development of Antedon (Comatula, *Lamk.*) rosaceus, pt. 1. Phil. Trans. Royal Soc., 1866, pp. 671-756, pls. xxxi-xliii.

CHAMBERLIN, T. C.

1883. Geological Survey of Wisconsin, Survey of 1873-1879. Vol. i, 1883, xxiv and 725 pp., 11 pls., 157 text-figs. Madison, Wis.

CHAMBERLIN, T. C., and SALISBURY, R. D.

1906. Geology, vol. 2, Earth History, 1906, xxvi and 692 pp., 306 text-figs. New York.

CHAPMAN, E. J.

1882, 1883. A Classification of Crinoids. Trans. of the Royal Soc. of Canada for the Years 1882 and 1883, pub. 1883, vol. i, sec. iv, pp. 113-116. Sep. May, 1882, pp. 1-5 and Recapitulation, but without Appendix.

CLARK, AUSTIN HOBART.

1908. Infrabasals in Recent Genera of the Crinoid Family Pentacrinitidae. Proc. U. S. Nat. Museum, vol. xxxiii, 1908, pp. 671-676, figs. 1-8. Washington, D. C.

1908. The Axial Canals of the Recent Pentacrinitidae. Proc. U. S. Nat. Mus., vol. xxxv, 1908, pp. 87-91, figs. 1-16. Washington, D. C.

1910. The Phylogenetic Interrelationships of Recent Crinoids. Proc. U. S. Nat. Mus., vol. 38, 1910, pp. 115-118. Washington, D. C.

1911. The Systematic Position of the Genus Marsupites. Proc. U. S. Nat. Mus., vol. 40, 1911, pp. 649-654. Washington, D. C.

1912. The Homologies of the So-called Anal, and Other Plates in the Pentacrinoid Larvae of the Free Crinoids. Jour. Washington Acad. Sci., vol. ii, no. 13, 1912, pp. 309-314. Washington, D. C.

1913. The Systematic Position of the Crinoid Family Plicatocrinidae. Washington Acad. Sci., vol. iii, no. 20, 1913, pp. 494-499.

1915. A Monograph of the Existing Crinoids. Vol. 1. Bull. 82, U. S. Nat. Mus., 1915, vi and 406 pp., 17 pls., 513 text-figs. Washington, D. C.

1919. The Systematic Position of the Crinoid genus Holopus. Jour. Washington Acad. Sci., vol. 9, pp. 136-138.

CLARKE, JOHN M.

1900. The Oriskany Fauna of Becraft Mountain, Columbia County, N. Y. Mem. New York State Museum, no. 3, vol. 3, 1900, 128 pp., 9 pls. Albany, N. Y.

CLARKE, JOHN M., and RUDEMANN, RUDOLPH.

1903. Catalogue of Type Specimens of Paleozoic Fossils in New York State Museum. New York State Mus., Bull. 65, Paleo. 8, 1903, 847 pp. Albany.

CLELAND, H. F.

1911. The Fossils and Stratigraphy of the Middle Devonic of Wisconsin. Wisconsin Geol. and Nat. Hist. Survey, Bull. no. 21 (Sci. Ser. no. 6), 1911, 222 pp., 57 pls., 5 text-figs.

CONRAD, T. A.

1842. Observations on the Silurian and Devonian Systems of the United States, with descriptions of new organic remains. Jour. Acad. Nat. Sci. Philadelphia, vol. viii, pt. ii, 1842, pp. 228-280, pls. xii-xvii. Philadelphia.

COOPER, W. F.

1888. Tabulated List of Fossils Known to Occur in the Waverly of Ohio. Bull. Sci. Lab. Denison University, vol. 4, pt. 1, 1888, pp. 123-129. Granville, Ohio.

DANIELSSEN, D. C.

1892. Crinoidea. Norske Nordhavs-Expedition, 1876-1878. XXI. Zoologi, 1892, 28 pp., 5 pls. and map, 4to. Christiania.

DEWALQUE, G.

1883-1884. See Fraipont.

DODERLEIN, LUDWIG.

1907. Die Gestielten Crinoiden der Siboga-Expedition. Resultats des Explorations en 1899-1900, a bord du Siboga. Monograph no. 42a, 1907, 54 pp., 23 pls., 7 text-figs. Leiden.

1912. Die gestielten Crinoiden der Deutschen Tiefsee-Expedition. Abdruck aus. Wissenschaftliche Ergebnisse der Deutschen Tiefsee-Expedition auf dem Danfer "Valdivia," 1898-1899. Band 17, 1st Heft, 1912, pp. 1-34, pls. 1-12. Jena.

EICHWALD, EDOUARD D'.

1860. Animaux rayonnes (Echinoderma). Lethaea Rossica ou Paleontologie de la Russie. Vol. 1, 8vo, seconde section de l'ancienne periode, 1860, pp. 572-661. Atlas Ancienne Periode, 4to, pls. xxxi-xxxiii. Stuttgart.

Ellis, John.

1762. An Account of an Encrinus, or Starfish, with a jointed stem, taken on the coast of Barbadoes, which explains to what kind of animals those fossils belong, called Starstones, Asteriae and Astropodia, which have been found in many parts of this kingdom: In a letter to Mr. Emanuel Mendes da Costa, F. R. S. Phil. Trans., lii, pt. i, for 1761, 1762, pp. 357-365, pls. xiii, xiv. London.

Fischer-de-Waldheim, Gotthelf.

1830, 1837. Oryctographie de Gouvernment de Moscou. Folio (pt. 1) 1830, i-ix, exp. of plates. Pls. A. G. 1-40 and 1-16. (Pt. 2) 1837, i-v, xi-xvii, and 202 pp., 54 pls., 1 portrait, 5 maps.

Foerste, A. F.

1901. Silurian and Devonian Limestones of Tennessee and Kentucky. Bull. Geol. Soc. America, vol. xii, 1901 (Oct.), pp. 395-444, pls. 35-41, 8 text-figs. Rochester.

1903. Silurian and Devonian Limestones of Western Tennessee. Jour. of Geol., vol. xi, nos. 6, 7, 1903 (Sept.-Oct.) (Oct.-Nov.), pp. 554-583, and 679-715, 10 text-figs. Chicago.

Follmann, Otto.

1882. Die unterdevonischen Schichten von Olkenbach. Verh. Nat. Hist. Ver preuss. Rheinl., ser. 4, ix, 1882, pp. 129-179. Bonn.

1887. Unterdevonische Crinoiden. Verh. Nat. Hist. Ver. preuss. Rheinl., ser. 5, iv, 1887, pp. 113-138, pls. ii-iii. Bonn.

Fraipont, Julien (Dewalque, G., in).

1883. Recherches sur les Crinoides du Famennien (Dévonien Supérieur) de Belgique. Annales de la Soc. géol. de Belg., t. x. Mémoires, 1883, pp. 45-68, pls. 2-5, 1 text-fig., sep. pub. 26 pp., pls. 2-5, 1 text-fig. Liége.

1884. Recherches sur les Crinoides du Famennien (Dévonien Supérieur) de Belgique. Annales de la Soc. géol. de Belg., t. xi. Mémoires, 1844, pp. 105-118, pl. 1, 2 text-figs., sep. 16 pp., pl. 1, 2 text-figs. Liége.

Geinitz, H. B.

1853. Die Versteinerungen der Greuwackenformation in Sachsen und den angrenzenden Länder-Abtheilungen. Hefte II, 1853, 95 pp., 20 pls. Leipzig.

Goldfuss, A.

1826, 1833. Petrefacta Germaniae. Abbildungen und Beschreibungen der Petrefacten Deutschlands und der angranzenden Lander. Vol. 1, 1826-1833, 252 pp. Atlas, 71 pls. Düsseldorf.

1839. Beiträge zur Petrefactenkunde: A Ueber Fossile Crinoideen. Nova Acta Akad., Leopoldina, vol. xix, i, 1839, pp. 329-352, pls. 30-32.

Grabau, Amadeus.

1901. Guide to the Geology and Paleontology of Niagara Falls and Vicinity. With a chapter on Post-Pliocene Fossils of Niagara by Elizabeth J. Letson. Bull. 45, N. Y. State Museum, vol. 9, 1901, 284 pp., 18 pls., 190 text-figs. Albany, N. Y.

Greger, D. K.

1909. The Devonian of Central Missouri. American Journal Science and Arts, vol. xxvii, 1909 (May), pp. 374-378. New Haven.

Hall, James.

1843. Natural History of New York, vol. iv, pt. 4, survey of the Fourth Geological District, 1843, xxii and 683 pp., 19 pls., map, 74 tables. Albany, N. Y.

1852. Natural History of New York, Paleontology, vol. ii. Organic Remains of Lower Middle Division of the New York System. 1852, viii and 362 pp., 104 pls. (in i-lxxxiv). Albany, N. Y.

1858. (Report of) The Geological Survey of the State of Iowa: Embracing the Results of Investigations Made During Portions of the Years 1855, 1856 and 1857. Vol. i, pt. ii, Palaeontology, 1858, pp. 473-724, 29 pls., text-figs. 53-118. Albany, N. Y.

1858. Crinoids of New York. (An advance notice of vol. 3, Paleontology of New York.) American Jour. Sci. & Arts, ser. 2, vol. xxv, March, 1858, pp. 277-279.

1859. Geological Survey of New York. Palaeontology: vol. iii. Containing descriptions and figures of the organic remains of the Lower Helderberg Group and the Oriskany Sandstone. Pt. i, text, 1859, xii and 532 pp., pt. ii; plates, 1861, 142 pls. (in 1-120).

1860. Contributions to the Palaeontology of Iowa; being descriptions of new species of Crinoidea and other fossils. Geological Report of Iowa, vol. i, pt. ii, Supplement, 1860, iv and 92 pp., 3 pls., 44 figs. Albany (1859).

1861. Descriptions of New Species of Crinoidea from the Carboniferous Rocks of the Mississippi Valley. Jour. Boston Soc. Nat. Hist., vol. vii, 1861 (Jan.), pp. 261-328. Boston. Republished Aug., 1872, with 7 photographic plates. Photo. Plates N. Y. State Mus. N. H. Bull. i, pls. 1-7.

1861. Descriptions of New Species of Crinoidea and Other Fossils, from the Carboniferous Rocks of the Mississippi Valley. Adv. Abst. Boston Soc. Nat. Hist., vol. vii, 1861 (Feb. 25th), 18 pp.

1861. Descriptions of New Species of Crinoidea; from Investigations of the Iowa Geological Survey. Preliminary Notice, 1861 (Feb. 25), 18 pp. Albany, N. Y.

1861-2. Preliminary Notice of Some of the Species of Crinoidea Known in the Upper Helderberg and Hamilton Groups of New York. 15th Ann. Rept. Regents. Univ. N. Y. on Conditions of State Cabinet of Natural History, 1862, pp. 115-153, pl. 1, 6 figs. Separate 1861-2, pp. 87-125, pl. 1, 6 figs. Senate Doc. No. 116, 1862, pp. 115-153, figs.

1863. Preliminary Notice of Some Species of Crinoidea from the Waverly Sandstone Series of Summit County, Ohio, supposed to be of the age of the Chemung group of New York. Printed in advance, from 17th Rept. on the New York State Cabinet, 1863 (Nov.), 11 pp.

1864. *Ibid.* 17th Ann. Rept. Regents, Univ. N. Y., on Condition of State Cabinet of Natural History, 1864, pp. 50-60.

1864. Description of New Species of Fossils from the Carboniferous Limestones of Indiana and Illinois. Trans. Albany Inst., vol. iv, 1864, pp. 1-35. Albany. Advance Pub. 1856, pp. 1-35.

1864. Notice of Some New Species of Fossils from a Locality of the Niagara Group in Indiana, with a list of identified species from the same place. Trans. Albany Institute, vol. iv, 1864, Albany, pp. 195-228. Advance publication, 1863 (May), pp. 1-34.

1864, 1865. Account of Some New or Little Known Species of Fossils from Rocks of the Age of the Niagara Group. Adv. Pub. for 18th Ann. Rept. New York State Cab. Nat. Hist., 1864 (Dec.), pp. 1-16, pl. 1, 1865 (Jan.), pp. 17-47, 12 figs.

1868. *Ibid.* 20th Ann. Rept. State Cab. Nat. Hist. of New York (1867), 1868, pp. 305-401, 16 figs., pls. 10-23. Albany, N. Y.

1870. Descriptions of New or Little Known Species of Fossils from Rocks of the Age of the Niagara Group. 20th Ann. Rept. New York State Cab. Nat. Hist., Rev. Ed., 4to, Imprint 1868, 1870, pp. 347-438, pls. 10-25. Albany, N. Y.

1872. Photographic Plates, New York State Mus. N. H. Bull. i, 1872 (August), 7 pls., see 1861.

1872. Description of New Species of Crinoidea and Other Fossils from Strata of the Age of the Hudson River Group and the Trenton Limestone. 24th Ann. Rept. on the New York State Mus. Nat. Hist., 1872, pp. 205-224, pls. 2, 5, 6-8. Albany, N. Y.

1879. The Fauna of the Niagara Group in Central Indiana. 28th Ann. Rept. New York State Museum of Natural History, Mus. Ed. 1879, pp. 99-203, pls. 3-34, 8 figs. Albany, N. Y.

1882. Descriptions of the Species of Fossils Found in the Niagara Group at Waldron, Indiana. 11th Ann. Rept. Dept. Geol. & Nat. Hist., Indiana, for 1881, 1882, pp. 217-345, pls. 1-36, 12 figs. Indianapolis.

Hall, James, and Whitfield, R. P.

1875. Descriptions of Invertebrate Fossils Mainly from the Silurian System. (Report of) The Geological Survey of Ohio, vol. ii, pt. ii, sect. i, 1875, pp. 65-179, pls. 1-13. Columbus.

Hamann, Otto.

1905-7. Bronn's Klassen und Ordnungen des Tier-Reichs, wissenschaftlich dargestellt in Wort und Bild. Zweiter Band, 3 Abteilung, Echinodermen (Stachelhauter) (Begonnen von H. Ludwig). V. Buch. Die Seelilien, 1905-7, ii and pp. 1415-1602, 13 taf., 22 text-figs. Leipzig, Jan., 1905, pp. 1415-1494, pls. 1-4, 17 text-figs.; Feb., 1906, pp. 1495-1558, pls. 5-8. text-figs. 18-22; 1907, pp. 1559-1602, pls. 9-13.

Herrick, C. L.

1891. The Cuyahoga Shale and the Problem of the Ohio Waverly. Bull. Geological Soc. of America, vol. 2, 1891, pp. 31-48, pl. 1. New York.

Hisinger, Wilhelm.

1819-40. Anteckningar i Physik och Geognosi und resor uti Sverige och Norrige. Sjunde Haftet, 1840, 147 pp.

1837-41. Lethaea suecica seu petrificata sueciae, iconibus et characteribus illustrata. 4to, 1837, 124 pp., pls. A, B, C, i-xxxvi, Supplementum secundum, 1840, 11 pp., pls. 37-39. Supplement secundi continuatio, 1841, 6 pp., pls. 40-42. Holmiae.

Jaekel, Otto.

1891. Ueber Holopocriniden mit besonderer Berucksichtigung der Stamberger Formen. Zeitschr. der Deutschen geol. Gesellschaft, xliii, Hefte 3, 1891 (July, August, Sept.), pp. 557-670, pls. xxxiv-xliii. Berlin.

1894. Entwurf einer Morphogenie und Phylogenie der Crinoiden. Sitsber. Ges. naturf. Freunde Berlin, Jahrg. 1894, no. 4, pp. 101-121. Berlin.

1897. Ueber einige palaozoische Gattungen von Crinoiden. Abdruck a. d. Zeitschr. d. Deutsch. geolog. Gesellschaft, Bd. 49, Jahrg. 1897, pp. 44-48, figs. a-c.

1898. Ueber einen neuen devonischen Pentacrinoiden. Abdruck a. d. Zeitschr. d. Deutsch. geolog. Gesellschaft, Bd. 50, Jahrg. 1898, pp. 28-32, 5 figs.

1899. Stammesgeschichte der Pelmatozoen. I Thecoidea und Cystoidea, 4to, 1899, x and 442 pp., 18 pls., 88 text-figs.

1904. Ueber einen Pentacriniden des deutschen Kreide. Sitzungs-Berichten des Gesellschaft naturforschender Freunde, Jahrg. 1904, Nr. 9, pp. 191-196, 1 pl. Berlin.

Keyes, C. R.

1894. Paleontology of Missouri, pt. i. Missouri Geolog. Surv. vol. iv, pt. i, 1894, pp. 1-127, pls. 1-32. Chap. viii, Crinoidea, pp. 143-225, pls. xix-xxxi. Jefferson City.

1902. Devonian Intervals in Missouri. Bull. Geol. Soc. America, vol. 13, 1902 (August), pp. 267-292, pl. 44. Rochester.

Kindle, E. M.

1896. The Relation of the Fauna of the Ithaca Group to the Faunas of the Portage and Chemung. Bull. Amer. Pal., vol. ii, 1896, no. 6 (Dec.), pp. 3-54, pl. 1. Ithaca, N. Y.

Kirk, Edwin.

1911. The Structure and Relationships of Certain Eleutherozoic Pelmatozoa. Proc. U. S. Nat. Mus., vol. 41, 1911, pp. 1-137, pls. 1-11.

Koninck, L. G. de, and Le Hon, H.

1853-54. Recherches sur les Crinoides du Terrain Carbonifere de la Belgique. Mém. Acad. Roy. Belgique, vol. xxvii, 1853, Mém. 3, 215 pp., vii pls., 20 figs.; 2d 1854, 205 pp., 7 pls., 20 figs. (*Pagination of text unchanged.*) Bruxelles.

Llhuyd (Luidius), Edwardus.

1699. Lithophylacii Britannici Ichnographia. 1699, xv and 139 pp., 23 pls. London.

1760. Lithophylacii Britannici Ichnographia, etc. Editio Altera 1760, xviii and 156 pp., 25 pls., text-figs. not numbered, pp. 101, 122, 123, 130, 142. Oxonii.

Loriol, P. de.

1882-1884. Paléontologie Francaise ou Description des Fossils de la France. 1re serie. Animaux Invertébrés. Terraine Jurassique tome xi, 1re partie. Crinoides. Atlas, 1882-1884, 121 pls. Paris.

1894. Notes pour servir a l'étude des Echinodermes, IV. Revue Suisse de Zoology, tome ii, 1894, pp. 467-497, pls. 22-24. Geneve.

Lyon, Sidney S., and Casseday, S. A.

1859. Description of Nine New Species of Crinoidea from the Subcarboniferous Rocks of Indiana and Kentucky. American Jour. of Sci. & Arts (2), vol. 28, no. 83, 1859 (Sept.), pp. 233-246. New Haven, Conn.

1860. Description of Nine New Species of Crinoidea from the Subcarboniferous Rocks of Indiana and Kentucky. American Jour. Sci. & Arts (2), vol. 29, Imprint 1859, 1860 (Jan.), pp. 68-78. New Haven, Conn.

M'Coy, Frederick.

1844. A Synopsis of the Characters of the Carboniferous Limestone Fossils of Ireland. 1844, fol., viii and 207 pp., xxix pls. Dublin.

1850. On Some New Genera and Species of Silurian Radiata in the Collection of the University of Cambridge. Ann. & Mag. Nat. Hist. (2), vi, 1850, pp. 270-290.

1854. Silurian Radiata. Contributions to British Palaeontology, etc. Chap. vii, 1854, pp. 154-177. Cambridge.

Meek, F. B.

1873. Descriptions of Invertebrate Fossils of the Silurian and Devonian Systems. Rep. Geol. Survey of Ohio, vol. 1, pt. 2, Paleontology, sect. 1, 1873, pp. 1-243, pls. 1-23. Columbus.

1874. Notes on Some of the Fossils Figured in the Recently Issued Fifth Volume of the Illinois State Geological Report. Amer. Jour. Sci. & Arts (3), vii, 1874 (March, April, May, June), pp. 189-193, 369-376, 484-490, 580-584. New Haven, Conn.

Meek, F. B., and Worthen, A. H.

1860. Descriptions of New Species of Crinoidea and Echinoidea from the Carboniferous Rocks of Illinois and Other Western States. Proc. Acad. Nat. Sci. Philadelphia (2), iv, 1860 (Sept.), pp. 379-397.

1862. Descriptions of New Palaeozoic Fossils from Illinois and Iowa. Proc. Acad. Nat. Sci. Philadelphia (2), xiii (June, 1861), 1862, pp. 128-148.

1865. Remarks on the Genus *Taxocrinus* (Phillips), M'Coy, 1844, and Its Relations to *Forbesiocrinus,* Koninck and Le Hon, 1854, with descriptions of new species. Proc. Acad. Nat. Sci. Philadelphia (2), ix, 1865 (Aug.), pp. 138-143.

1866. Contributions to the *Paleontology* of Illinois and Other Western States. Proc. Acad. Nat. Sci. Philadelphia (1), xviii, (2) x, 1866 (July), pp. 251-275.

1866. Descriptions of Invertebrates from the Carboniferous System. Geol. Surv. of Illinois, vol. ii, Pal., 1866, pp. 143-411, pls. 14-20, 23-32, figs. 3-39. Springfield.

1868. Palaeontology of Illinois. Geol. Sur. of Illinois, vol. iii; Geol. & Pal., 1868, pp. 288-565, pls. 1-20, 74 figs. Springfield.

1868. Remarks on Some Types of Carboniferous *Crinoidea,* with descriptions of new genera and species of the same, and of one *Echinoid.* Proc. Acad. Nat. Sci. Philadelphia (1), xx, 1868, pp. 335-359. Philadelphia.

1873. Descriptions of Invertebrates from the Carboniferous System. Geol. Surv. of Illinois, vol. v, pt. ii, 1873, pp. 320-619, pls. 1-32. Springfield.

1875. Descriptions of Invertebrates. Geol. Surv. of Illinois, vol. vi, pt. ii, sec. ii, 1875, pp. 489-532, pls. 23-33, 3 figs. Springfield.

Miller, J. S.

1821. A Natural History of the Crinoidea or Lily-shaped Animals, with observations on the genera Asteria, Euryale, Comatula and Marsupites, 4to, 1821, viii and 150 pp., 50 pls. Bristol.

Miller, S. A.

1881. New Species of Fossils and Remarks upon Others from the Niagara Group of Illinois. Jour. Cincinnati Soc. Nat. Hist., vol. 4, no. 2, 1881 (July), pp. 166-176, pl. iv. Sep. pub. 1881, pp. 1-11, pl. iv.

1889-97. North American Geology and Palaeontology for the Use of Amateurs, Students, and Scientists. 8vo, 1889, 664 pp., 1194 figs. 1st Appendix, 1892, pp. 665-718, figs. 1195-1265. 2d Appendix, 1897, pp. 719-793, figs. 1266-1457. Cincinnati.

1891. A Description of Some Lower Carboniferous Crinoids from Missouri. Bull. no. 4, Geol. Surv. of Missouri, 1891, 40 pp., 5 pls. Jefferson City.

1891. Palaeontology. 17th Rept. Geol. Surv. Indiana, Adv. Sheets, 1891, pp. 1-103, pls. 1-20. Final, 1892, pp. 611-705, pls. 1-20.

1892. Palaeontology. 18th Rept. Geol. Surv. Indiana, Adv. Sheets, 1892 (Sept.), pp. 1-79, pls. 1-12. Indianapolis. Final (1891), 1892, pp. 611-705, 20 pls. Indianapolis.

Miller, S. A., and Gurley, W. F. E.

1890. Description of Some New Genera and Species of Echinodermata from the Coal Measures and Subcarboniferous Rocks of Indiana, Missouri and Iowa. Jour. Cincinnati, Soc. Nat. Hist., vol. xiii, 1890 (Apr.), pp. 3-25, pls. 1-4. Authors' ed. enlarged, 1890 (June), pp. 3-59, pls. 1-10. 16th Ann. Rept. Dept. Geol. Nat. Hist. of Indiana, for 1888, 1890, pp. 327-373, pls. 1-10. Indianapolis.

1894. Description of Some New Species of Invertebrates from the Palaeozoic Rocks of Illinois and Adjacent States. Bull. no. 3, Illinois State Mus. Nat. Hist., 1894, pp. 1-81, pls. 1-8. Springfield.

1894. Upper Devonian and Niagara Crinoids. Bull. no. 4, Illinois State Mus. Nat. Hist., 1894 (Oct.), 37 pp., 3 pls. Springfield.

1894. New Genera and Species of Echinodermata. Bull. no. 5, Illinois State Mus. Nat. Hist., 1894 (Dec.), 53 pp., 5 pls. Springfield.

1895. Description of New Species of Palaeozoic Echinodermata. Bull. no. 6, Illinois State Mus. Nat. Hist., 1895 (April), 62 pp., 5 pls. Springfield.

1895. New and Interesting Species of Palaeozoic Fossils. Bull. no. 7, Illinois State Mus. Nat. Hist., 1895 (Dec.), 89 pp., 5 pls. Springfield.

1896. Description of New and Remarkable Fossils from the Palaeozoic Rocks of the Mississippi Valley. Bull. no. 8, Illinois State Mus. Nat. Hist., 1896 (Feb.), 65 pp., 5 pls. Springfield.

1896. New Species of Crinoids from Illinois and Other States. Bull. no. 9, Illinois State Mus. Nat. Hist., 1896 (April), 66 pp., 5 pls. Springfield.

1897. New Species of Crinoids, Cephalopods and Other Palaeozoic Fossils. Bull. no. 12, Illinois State Mus. Nat. Hist., 1897 (Jan.), pp. 5-69, pls. 1-5. Springfield.

Minchin, E. A.

1891. Echinodermata. Zoological Record, 1891, vol. xxviii.

Morris, John.

1843, 1854. A Catalogue of British Fossils, etc. 1st ed., 8vo, 1843, xii and 222 pp.; 2d ed., 8vo, 1854, viii and 372 pp. London.

Mortensen, Th.

1910. Report on the Echinoderms Collected by the Danmark-Expedition at Northeast Greenland, Danmark-Ekspeditionentil Gronlands Nordostkyst 1906-1908, Bind V, Nr. 4 (Copenhagen, 1910), pp. 239-302, pls. 8-17, 7 text-figs. Copenhagen.

Müller, Johannes.

1843. Ueber den Bau des *Pentacrinus caput Medusae.* Abhandl. Akad. d. Konigl. Wiss. Berlin, Physik-math. Kl. vol. for 1841, 1843, pp. 177-248, vi pls.

Abst. Monatsber, K. Preuss. Akad. Wiss. Berlin, 1840, pp. 88-106; Wigemann's Archiv. f. Naturgesch., 1840, Bd. I, pp. 307-318; Separate 1843, pp. 1-72, pls. 1-6. Berlin.

1856-57. Ueber neue Crinoiden aus dem Eifler Kalk. Monatsber. d. Konigl. Akad. Wiss. Berlin, Physik-Math. Kl. 1856, pp. 353-356. Berlin.

Abst. 4to, 1857, pp. 243-268, pls. 1-4, containing several important differences in names, etc.

1858-59. Ueber einige Echinodermen der Reinischen Grauwache und des Eifler Kalkes. Monatsber. d. Konigl. Akad. Wiss. Berlin (March, 1858), 1859, pp. 185-198. Berlin.

Murchison, R. I.

1839. The Silurian System, etc. 1839, xxxii and 786 pp., 40 pls. (31 of fossils, 9 of sections), 112 woodcuts (Crinoidea by J. Phillips). London.

1859. Siluria. The History of the Oldest Fossiliferous Rocks and Their Foundations, with a brief sketch of the distribution of gold over the earth. 3d ed., 1859, xix and 592 pp., 41 pls., 90 text-figs. on fossils. London.

Oehlert, Daniel.

1878-79. Descriptions de deux nouveaux genres de Crinoides du terrain dévonien de la Mayenne. Extrait du Bull. de la Soc. Géol. de France (3), vii, 1878, pp. 1-5, pls. 1, 2. Bull. de la Soc. (3), vii, 1879, pp. 6-10, pls. 1, 2 for Nov. 4, 1878. Paris.

1882. Crinoides nouveaux du Dévonien de la Sarthe et de la Mayenne. Bull. de la Soc. Géol. de France (3), x, 1882, pp. 352-363, pls. 8, 9. Paris.

Ohern, D. W.

1913. Systematic Paleontology of the Lower Devonian Deposits of Maryland; Crinoidea. Maryland Geol. Surv., Lower Devonian, 1913, pp. 249-258, pls. 36-40 (in plate volume). Baltimore, Md.

Orbigny, Alcide d'.

1849-52. Cours élémentaire de Paléontologie et de Géologie stratigraphiques. 12mo, vol. 1, 1849, 299 pp., 165 figs., vol. 2, 1851; fas. 1, 382 pp., figs. 166-392, vol. 2, 1852; fas. 2, pp. 383-847, figs. 393-628. Atlas, 4to, 1852, 17 tables. Paris.

1849-52. Prodrome de Paléontologie Stratigraphique Universelle des Animaux Mollusques and Rayonnés (faisant suit au Cours Élémentaire de Paléontologie, et de Géologie Stratigraphiques), vol. 1, 1849, lx and 394 pp., vol. 2, 1850, 427 pp., vol. 3, 1852, 192 pp. Paris.

Pacht, Raimund.

1852. Dimerocrinus Oligoptilus: ein beitrage zur kenntniss der Gattung Dimerocrinites. Ver. Russ. Kaiserlich. Min. Gesell zu St. Petersburg. Jahrg. 1852-53, pp. 339-375. Separate pp. 1-31, 3 tabs., 1852.

Parkinson, James.

1832. Organic Remains of a Former World. An examination of the mineralized remains of vegetables and animals of the antediluvian world, generally termed extraneous fossils. 2d, 1832, vol. i, The Vegetable Kingdom, xii and 460 pp., 9 pls., and frontispiece. Vol. 2, The Fossil Zoophytes, xiv and 286 pp., 19 pls., and frontispiece. Vol. 3, The Fossil Starfish, Echini, Shells, Insects, Amphibia, Mammalia, etc., xii and 467 pp., 22 pls. and frontispiece. London.

Pate, W. F., and Bassler, R. S.

1908. The Late Niagaran Strata of West Tennessee. Proc. U. S. Nat. Mus., vol. 34, 1908, pp. 407-432. Washington, D. C.

Phillips, John.

1836. Description of Fossils in the Mountain Limestone Formation of Yorkshire and Some Other Districts Arranged According to their Natural Affinities, with notices of the strata in which each species occurs, and of localities where they are found. Illustrations of the Geology of Yorkshire. 3d ed., 4to, vol. ii, The Mountain Limestone District, 1836, chap. vii, pp. 194-244, pls. 3, 4.

1841. Figures and Descriptions of the Palaeozoic Fossils of Cornwall, Devon, and West Somerset, observed in the course of the Ordnance Geological Survey of the District. 8vo, 1841, xii and 231 pp., 60 pls. London.

Pictet, F. J.

1853-57. Traite de Paléontologie ou Histoire Naturelle des Animaux Fossiles considérés dans leurs rapports Zoologiques et Géologiques. 8vo, 2d ed., tome 4, Crinoides, 1857, pp. 278-345, Atlas, 4to, pp. 66-69, pls. 99-102. Paris.

Quenstedt, F. A.

1852-1885. Handbuch der Petrefactenkunde. 8vo, 1852, iv and 792 pp., 62 pls. Dritte Auflage, 4 Abth., 1885, pp. 801-988, pls. 63-80, figs. 292-374. Tubingen.

1874-76. Die Asteriden und Encriniden nebst Cysti- und Blastoideen, Petrefactenkunde Deutschlands. 1 Abth., vol. iv, 8vo, 1874-76, viii and 742 pp., Atlas pls. 90-114. Leipzig.

Ringueberg, E. N. S.

1886. New Genera and Species of Fossils from the Niagara Shales. Bull. Buffalo Soc. Nat. Sci., vol. v, no. 1, 1886, pp. 5-22, pls. 1, 2. Buffalo.

1890. The Crinoidea of the Lower Niagara Limestone at Lockport, N. Y., with new species. Ann. New York Acad. Sci., vol. 5, nos. 7, 8, 1890 (July), pp. 301-306, pl. 3. New York.

Roemer, C. F.

1844. Das Reinische Uebergansgebirge. Eine palaeontologisch-geognostiche Darstellung. 4to, 1844, 96 pp., 6 pls. Hanover.

1851, 1852. Beitrage zur Kenntniss der fossilen Fauna des Devonischen Gebirges am Rhein. Verhandl. des naturhist. Ver der preuss. Rheinl. 8, Jahrg. 1851, pp. 357-376; 9, Jahrg. 1852, pp. 281-288, pls. 7, 8; Sep. pp. 1-20, pls. 1, 2, 1851. Bonn.

1860. Die Silurische Fauna des Westlichen Tennessee. Eine Palaeontologische Monographie. 4to, 1860, vii and 100 pp., 5 pls. Breslau.

1863. Neue Astriden und Crinoiden aus Devonischen Dachschiefer von Bundenbach bei Birkenfeld. Palaeontographica, ix (4), 1863 (Feb.), pp. 143-152, pls. 23-29.

Roemer, F., in Bronn.

1852-54. See Bronn, 1851-6.

Rofe, John.

1873. Further Notes on Crinoidea. Geol. Mag. dec. 1, vol. x, 1873, pp. 262-267, pl. 11.

Rowley, R. R.

1893. Description of Some New Species of Crinoids, Blastoids, and Brachiopods, from the Devonian and Sub-Carboniferous Rocks of Missouri. American Geologist, vol. xii, 1893, pp. 303-309, pl. 14.

1894. New Species of Crinoids and Brachiopods from the Missouri Hamilton. American Geologist, vol. xiii, 1894, pp. 151-154, figs. 1-10.

1895. Description of a New Genus and Five New Species of Fossils from the Devonian and Sub-Carboniferous Rocks of Missouri. American Geologist, vol. xvi, 1895, pp. 217-223.

1904. The Echinodermata of the Missouri Silurian and a New Brachiopod. American Geologist, vol. xxxiv, 1904, pp. 269-282, pl. 16.

Salter, J. W.

1873. A Catalogue of the Collection of Cambrian and Silurian Fossils contained in the Geological Museum of the University of Cambridge. 4to, 1873, xlviii and 204 pp., with portrait (Adam Sedgwick) and figures. Cambridge.

Sandberger, Guido, and Sandberger, Fridolin.

1850-56. Die Versteinerungen des Reinischen Schichtensystems in Nassau. 4to, 1850-56, xx and 564 pp., 41 pls., text-figs., 50 maps, 1 folding table. Crinoidea, pp. 383-402, 8 text-figs., pl. 35.

Sars, M.

1868. Mémoires pour servir à la connaissance des Crinoides, vivants. 4to, 1868, 65 pp., vi pls. Christiania.

Schlotheim, E. F., von.

1822-23. Nachtrage zur Petrefactenkunde. Abth. I, and 100 pp., 21 taf., 1822. Abth. 2, 114 pp., taf. 22-37, 1823. Separate pp. 1-118, taf. 1-13 (p. 40).

1832. Merkwürdige Versteinerungen aus der Petrefactensammlung. 8vo, 1832, iv and 40 pp. Versteinerungen aus v. Schlotheim's Sammlung, Heft I, A, taf., 1-29; Heft II, B, taf. 1-37.

Schlüter, Clemens.

1878. Ueber einige astylide Crinoiden. Besonderer Abdruck aus der Deutschen geologischen Gesellschaft. Jahrg. 1878, pp. 28-66, pls. 1-4.

Schultze, Ludwig.

1866, 1867. Monographie der Echinodermen des Eifler Kalkes. 4to, Lenkschr. k. Akad. Wien. Math.-nat. Kl., vol. xxvi, 1867, pp. 113-230, pls. 1-13. Separate, 118 pp., 13 taf. Wien, 1866.

Sedgwick, Adam, and M'Coy, Frederick.

1854. A Synopsis of the Classification of the British Palaeozoic Rocks (Sedgwick), with a systematic description of British Palaeozoic Fossils in the Geological Museum of the University of Cambridge (M'Coy). 4to, 1854, xcviii, viii and 661 pp., Sup. i-viii, 25 pls. (IA-I, K, L; IIA-D; IIIA-I, K). Cambridge.

Seeliger, Oswald.

1893. Studien zur Entwicklungsgeschichte der Crinoiden (*Antedon rosacea*). Zool. Jahrb. Abth. f. Morph., vol. vi, for 1892, 1893, pp. 161-444, pls. xii-xx, 12 figs. Jena.

Shumard, B. F.

1866. A Catalogue of the Palaeozoic Fossils of North America. Trans. Acad. Sci. St. Louis, vol. ii, no. 2, 1866, pp. 334-407.

Sladen, W. P.

1878. On the Genus Poteriocrinus and Allied Forms. Proc. West Riding Geol. & Polytech. Soc., N. S. I, 1878, pp. 242-253, pl. 10. Leeds.

Springer, Frank.

1901. Uintacrinus: Its Structure and Relations. Mem. Mus. Comp. Zool. Harvard College, vol. 25, no. 1, 1901 (August), 89 pp., 8 pls., 26 text-figs. Cambridge, Mass.

1902. On the Crinoid Genera Sagenocrinus, Forbesiocrinus, and Allied Forms. American Geologist, vol. 30, 1902, pp. 88-97, 1 fig.

1905. Cleiocrinus. Mem. Mus. Comp. Zool. Harvard College, vol. xxv, no. 2, 1905, pp. 93-114, pl. i. Cambridge, Mass.

1906. Discovery of the Disk in Onychocrinus and Further Remarks on the Crinoidea Flexibilia. Jour. Geology, vol. xiv, no. 6, 1906 (Sept.-Oct.), pp. 467-523, pls. 4-7. Chicago.

1909. A New American Jurassic Crinoid. Proc. U. S. Nat. Mus., vol. xxxvi, 1909 (March), pp. 179-190, pl. 4. Washington, D. C.

1911. Some New American Fossil Crinoids. Mem. Mus. Comp. Zool., Harvard College, vol. 25, no. 3, 1911, pp. 117-161, pls. 1-6. Cambridge, Mass.

1911. On a Trenton Echinoderm Fauna at Kirkfield, Ontario. Mem. Geol. Surv. Canada, no. 15-P, 1911, pp. 1-50, pls. 1-5. Ottawa.

1917. On the Crinoid Genus Scyphocrinus and Its Bulbous Root Camarocrinus. Smithsonian Institution, 1917, 74 pp., 9 pls., 18 text-figs. Washington, D. C.

Steinmann, Gustav.

1908. Die geologischen Grundlagen der Anstammungslehre. 1908, x and 284 pp. Leipzig.

Talbot, Mignon.

1905. Revision of the New York Helderbergian Crinoids. American Jour. Sci. & Arts (4), vol. 20, no. 115, 1905 (July), pp. 17-34, pls. 1-4, 4 text-figs.

Thompson, J. V.

1827. Memoir on the *Pentacrinus europæus.* 4to, 1827, pp. 1-12, 2 pls. Cork.

1836. Memoir on the Star-Fish of the genus Comatula, demonstrative of the *Pentacrinus europæus* being the Young of our Indigenous Species. Edinburgh New Philosophical Journal, vol. xx, 1836, pp. 295-300, with a plate. Edinburgh.

Thomson, Wyville.

1865. On the Embryogeny of Antedon rosaceus, *Linck* (Comatula rosacea of Lamarck). Phil. Trans. Royal Soc., 1865, pp. 513-544, pls. 23-27, text-figs. A-C. London.

Trautschold, Hermann.

1867. Einige Crinoideen und andere Thierreste des jüngeren Bergkalks im Gouvernment Moskau. Bull. Soc. Imp. Nat. Moskau, vol. 40, pt. 2, no. 3, 1867, pp. 1-49, pls. 1-4.

1879. Die Kalkbrüche von Mjatschkowa. Eine Monographie des Oberen Bergkalks. Nouv. Mem. Soc. Nat. Moscau, vol. 14, 1879, pp. 101-180, pls. 12-18.

Troost, Gerard.

1849. Geographical Survey of Tennessee. American Jour. Sci. & Arts (2), viii, 1849, pp. 419-421.

1850. A List of the Fossil Crinoids of Tennessee. Proc. Amer. Assoc. Adv. Sci., vol. 2, 1850, pp. 59-64. Boston.

Ure, David.

1793. The History of Rutherglen and East-Kilbride. Published with a view to promote the study of antiquity and natural history. 8vo, vi and 344 pp., 20 pls. Glasgow.

Waagen, W., and Jahn, J.

1899. Classe des Echinodermes. Famille des Crinoides. Syst. sil. Centr. Boheme. J. Barrande, Cont. edit. Musée Boheme, vol. 7, pt. ii, 1899, v and 215 pp., pls. 40-79, figs. 1-33, 6 diagrams. Prague.

Wachsmuth, Charles.

1877-78. Notes on the Internal and External Structure of Paleozoic Crinoids. American Jour. Sci. & Arts (3), xiv, 1877, pp. 115-127, and 181-191. New Haven. Rep. Ann. & Mag. Nat. Hist. (5), i, 1878, pp. 379-392, and 453-463.

Wachsmuth, Charles, and Springer, Frank.

1878. Transition Forms in Crinoids, and Descriptions of Five New Species. Proc. Acad. Nat. Sci. Philadelphia, 1878, pp. 224-266. Two photographic plates were issued with the authors' reprints (not published).

1879-86. Revision of the Palaeocrinoidea. Pt. 1, Proc. Acad. Nat. Sci. Philadelphia, 1879 (Nov. 4), pp. 226-378, pls. 15-17. Separate repaged, pp. 1-153, pls. 1-3 (xv-xvii). Pt. 2, *ibid.*, 1881, pp. 177-411, pls. 17-19. Separate repaged double pagination, 1-237, pls. 17-19. Pt. 3, sect. 1, 1885, pp. 225-36, pls. 4-9. Separate double pagination, pp. 1-138, pls. 4-9. Pt. 3, sect. 2, 1886, pp. 64-226. Separate double pagination continuous with first section, pp. 139-302, with index 303-334.

1888. Discovery of the Ventral Structure of Taxocrinus and Haplocrinus, and consequent modifications in the classification of Crinoidea. Proc. Acad. Nat. Sci. Philadelphia, xl, 1888 (Nov.), pp. 337-363, pl. 18.

1890. New Species of Crinoids and Blastoids from the Kinderhook Group of the Lower Carboniferous Rocks at Le Grand, Iowa. Geol. Survey of Illinois, vol. viii, pt. 2, sec. 2, 1890 (July), pp. 155-208, pls. xv-xvii.

1891. The Perisomic Plates of the Crinoids. Proc. Acad. Nat. Sci. Philadelphia for 1890, xlii (Feb.), 1891, pp. 245-392, pls. 9-10.

1897. The North American Crinoidea Camerata. Mem. Mus. Comp. Zool. Harvard College, vols. 20, 21, 1897, 838 pp., 83 pls., 21 text-figs. Tabs. A-C.

Weller, Stuart.

1896. Petalocrinus Mirabilis (n. sp.) and a New American Fauna. Jour. Geol., vol. iv, no. 2, 1896, pp. 166-173, pls. 6, 7, 2 text-figs. Chicago.

1898. The Silurian Fauna Interpreted on the Epicontinental Basis. Jour. Geol., vol. vi, no. 7, 1898 (Dec.), pp. 692-703, 2 text-figs.

1900. The Paleontology of the Niagaran Limestone in the Chicago Area. The Crinoidea. Bull. Chicago Acad. Sci., no. 4, pt. 1; Nat. Hist. Surv., 1900 (June 27), pp. 1-153, 15 pls., 57 text-figs. Chicago.

1903. The Paleozoic Faunas (of New Jersey). Geol. Surv. of New Jersey, Rept. on Paleontology, vol. 3, 1903, xi and 462 pp., 53 pls. Trenton, N. J.

Wenjukoff, P. N.

1886. Die Fauna des devonischen Systems im nordwestlichen und centralen Russland. Geol. Cab. der Kaiserlichen Univ. zu St. Petersburg. 8vo, 1886, pp. 419-707, 11 pls., pp. i-xvi, résumé in German.

Wetherby, A. G.

1879. Descriptions of New Species of Crinoids from the Kaskaskia Group of the Subcarboniferous. Jour. Cincinnati Soc. Nat. Hist., vol. 2, 1879 (October), pp. 134-140, pl. 11.

Whidborne, G. F.

1896. A Preliminary Synopsis of the Fauna of the Pickwell Down, Baggy and Pilton Beds. Proc. Geol. Assoc., vol. 14, 1896 (Sept.), pp. 371-377.

1899. A Monograph of the Devonian Fauna of the South of England. Vol. 3, pt. 3. The Fauna of the Marwood and Pilton Beds of North Devon and Somerset. Palaeontographical Soc. London for 1898, 1899, pp. 179-236, pls. 22-38.

White, C. A.

1862-63. Observations on the Summit Structure of Pentremites, the structure and arrangement of certain parts of Crinoids, and descriptions of new species from the Carboniferous Rocks at Burlington, Iowa. Boston Jour. of Nat. Hist., vol. 7, no. 4, Final Pub. 1863, pp. 481-506. Separate, 1862.

1881. Fossils of the Indiana Rocks. 2d Ann. Rept. Dept. Stat. & Geol. of Indiana for 1880, 1881, pp. 471-522, pls. 1-11.

1881. Paleontology. Fossils of the Indiana Rocks. Indiana Geol. Rept., 1879-1880, 1881, ext. from 2d Ann. Rep. Bureau Stat. & Geol. (for 1880), pp. 103-154, pls. 1-11. Indianapolis.

1882. Fossils of the Indiana Rocks (no. 2). 11th Ann. Rept. Dept. Geol. & Nat. Hist. Indiana (for 1881), 1882, pp. 347-401, pls. 37-55. Indianapolis.

Whiteaves, J. F.

1889. On Some Fossils from the Hamilton Formation of Ontario, with a list of the species at present known from that formation and province. Geol. & Nat. Hist. Surv. of Canada. Contributions to Canadian Paleontology, vol. 1, pt. 2, Final, 1889 (August), pp. 91-125, pls. 12-16. Separate, 1887. Montreal.

1891. The Fossils of the Devonian Rocks of the Mackenzie River Basin. Geol. Surv. of Canada. Contributions to Canadian Pal., vol. 1, pt. 3, 1891 (May), pp. 197-253, pls. 27-32. Montreal.

Whitehurst, J.

1786. An Inquiry into the Original State and Formation of the Earth, deduced from facts and the laws of nature. 2d ed., considerably enlarged, and illustrated with plates. 4to, 283 pp., 7 pls., with portrait of John Whitehurst. London.

Whitfield, R. P.

1882. Geological Survey of Wisconsin. Survey of 1873-79, vol. iv, pt. 3; Paleontology, 1882, pp. 160-363, pls. 1-27. Madison.

1882. On the Fauna of the Lower Carboniferous Limestones of Spergen Hill, Ind., with a revision of the descriptions of its fossils hitherto published, and illustrations of the species from the original type series. Bull. Amer. Mus. Nat. Hist., vol. 1, no. 3, 1882 (October 20), pp. 39-97, pls. 6-9. New York.

1891. Contributions to Invertebrate Palaeontology. Anns. New York Acad. Sci., vol. 5, 1891, pp. 505-620, pls. 5-16. New York. Reprinted Rept. Geol. Surv. Ohio, vol. 7, 1893, pp. 407-492, 494, pls. 1-11. Columbus.

Whitfield, R. P., and Hovey, E. O.

1898-1901. Catalogue of the Types and Figured Specimens in the Palaeontological Collection of the Geological Department, Amer. Mus. Nat. Hist. Bull. Amer. Mus. Nat. Hist., vol. 11, pts. 1-4, 1898, 1899, 1900, 1901.

Williams, H. S.

1882. New Crinoids from the Rocks of the Chemung Period (Upper Devonian) of New York State. Proc. Acad. Nat. Sci., Philadelphia, 1882, pp. 17-34, pl. 1.

Wilson, Herrick E.

1916. Evolution of the Basal Plates in the Monocyclic Crinoidea Camerate. Jour. Geol., vol. 24, 1916, pp. 488-510, 534-53, 666-84, pls. 1-3, 10 text-figs. Chicago.

Winchell, Alexander, and Marcy, Oliver.

1865. Enumeration of Fossils Collected in the Niagara Limestone at Chicago, Illinois. Mem. Boston Soc. Nat. Hist., vol. 1, 1865 (Dec.), pp. 81-114, pls. 2, 3. Cambridge, Mass.

Witry, Everlange de.

1780. Mémoire sur les Fossiles du Tournais, et les pétrefactions en général, relativement à leur utilité pour la vie civile. Mémoires de l'Académie impériale et royale des sciences et belles-lettres de Bruxelles. Vol. iii, pp. 13-44, pls. 1-4.

Wood, Elvira.

1904. On New and Old Middle Devonic Crinoids. Smithsonian Misc. Coll., vol. 47, 1904 (August), pp. 56-84, pls. 15, 16, 9 text-figs. Washington, D. C.

1909. A Critical Summary of Troost's Unpublished Manuscript on the Crinoids of Tennessee. Bull. U. S. Nat. Mus., no. 64, 1909, iii and 150 pp., 15 pls., 1 portrait. Washington, D. C.

Worthen, A. H.

1882. Descriptions of Fifty-four New Species of Crinoids from the Lower Carboniferous Limestones and Coal Measures of Illinois and Iowa. Bull. no. 1, Illinois State Mus. Nat. Hist., 1882, pp. 1-38. Springfield.

1883. Description of Fossil Invertebrates. Geol. Surv. of Illinois, vol. vii, pt. ii, sec. 11, 1883 (May), pp. 265-322, pls. 27-31. Springfield.

1890. Description of Fossil Invertebrates. Geol. Surv. of Illinois, vol. viii, pt. ii, sec. i, 1890 (July), pp. 68-154, pls. 9-14, 17-27. Springfield.

Wright, James, Jr.

1912. On the Crinoids from the Lower Carboniferous Limestones of Invertiel, Fife. Trans. Edinburgh Geol. Soc., vol. 10, pt. 1 (1911-12), 1912 (Nov.), pp. 49-60, pls. 5-7.

1914. On the Occurrence of Crinoids in the Lower Carboniferous Limestones of Fife. Trans. Edinburgh Geol. Soc., vol. 10, pt. 2, 1914, pp. 148-162, pls. 18-21.

Zittel, Karl Alfred, von.

1879. Handbuch der Palaeontologie, I Bd., Palaeozoologie, I Bd., 1 Abth., 1879, pp. 308-560. München & Leipzig.

1895. Grundzüge der Palaeontologie (Palaeozoologie). 8vo, 1895, viii and 971 pp., 2048 text-figs. (Echinodermata, pp. 112-240.) München & Leipzig.

1910. Grundzüge der Palaeontologie (Palaeozoologie) neubeerbeitet von Dr. Ferdinand Broili, I. Abteilung, Invertebrata. 3d ed., 8vo, 1910, vi and 607 pp., 1414 text-figs. München and Berlin.

Zittel, K. A., and Eastman, C. E.

1896, 1900, 1913. Text-book of Palaeontologie. Vol. i, pt. 1, 1st ed., 8vo, 1896, 352 pp., 593 text-figs. (Echinodermata, pp. 122-250); vol. i, 1st ed., 1900, viii and 706 pp., 1476 text-figs. (Echinodermata, pp. 122-250); 2d ed., 8vo, 1913, x and 839 pp., 1594 text-figs. (Echinodermata, pp. 143-313).

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